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23 July 2013

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SUBJECT: AFCEC FA8903-08-D-8769-0337; Task Order 0337
MMR SPEIM/LTM/Optimization Program
CDRL #A001k
Final CS-10 2013 Technical Memorandum: Focused Feasibility Study for Remedial System Optimization

Dear Mr. Davis:

As directed by the Air Force Civil Engineer Center, CH2M HILL is hereby distributing copies of the *Final CS-10 2013 Technical Memorandum: Focused Feasibility Study for Remedial System Optimization* dated July 2013. Enclosed are four bound copies, one unbound copy, and three compact disc (CD) copies. Copies are also being sent to the appropriate agencies.

If you have any questions or comments, please contact (Rose Forbes) at (508) 968-4670, extension 5613.

Sincerely,

CH2M HILL

N. Tindall

Nigel Tindall, P.G.
Project Manager

Enclosures: (4 bound, 1 unbound & 3 CDs)

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Final CS-10 2013 Technical Memorandum: Focused Feasibility Study for Remedial System Optimization

July 2013

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ACRONYMS AND ABBREVIATIONS

AFCEC	Air Force Civil Engineer Center
BOMARC	Boeing Michigan Aerospace Research Center
COC	contaminant of concern
CO_2	carbon dioxide
CSM	conceptual site model
CS-10	Chemical Spill-10
ft	feet
GHG	greenhouse gas
gpm	gallons per minute
IP	In-Plume
IRAR	Interim Remedial Action Report
kWh	kilowatt hour
lbs	pounds
LTM	Long Term Monitoring
MCL	Maximum Contaminant Level
Mgal	million gallons
MMR	Massachusetts Military Reservation
msl	mean sea level
MTU	mobile treatment unit

ACRONYMS AND ABBREVIATIONS

PCE	tetrachloroethene
ROD	Record of Decision
SPEIM	System Performance and Ecological Impact Monitoring
SR	Sandwich Road
TCE	trichloroethene
UTES	Unit Training Equipment Site
µg/L	micrograms per liter
3D	three-dimensional

1.0 INTRODUCTION

This *Final CS-10 2013 Technical Memorandum: Focused Feasibility Study for Remedial System Optimization* is presented in support of the Air Force Civil Engineer Center (AFCEC) Installation Restoration Program at the Massachusetts Military Reservation (MMR) on Cape Cod. This final technical memorandum was prepared under AFCEC's 4P Contract Number FA8903-08-D-8769, Task Order 0337.

1.1 PURPOSE

This technical memorandum has been prepared to present the results of the Chemical Spill-10 (CS-10) 2013 remedial system optimization effort. Based on the results of the 2008-2012 data gap investigation, a recommendation to use the updated 2012 CS-10 groundwater flow model and 2012 trichloroethene (TCE) plume shell to evaluate optimized operating scenarios for the CS-10 In-Plume (IP) remedial system and the CS-10 Sandwich Road (SR) extraction fence was presented in the *Final CS-10 2012 Data Gap Investigation Technical Memorandum* (AFCEC 2013c). The objective of this optimization evaluation was to improve plume capture and to reduce aquifer restoration timeframe; taking into account AFCEC's commitment to consider more sustainable, cost-efficient solutions.

1.2 REPORT ORGANIZATION

This technical memorandum consists of six sections and four appendices. A description of the CS-10 remedial system and a summary of the results from the 2012 data gap investigation are included in Section 2. The remedial system optimization approach is presented in Section 3. Remedial system optimization results and implementation and lifecycle cost estimates for the optimized scenarios are presented in Section 4. Conclusions and recommendations are presented in Section 5. References are included in Section 6. A compact disc with groundwater transport model animations is included as **Appendix A**. A summary of infrastructure requirements for implementation of the optimized scenarios is included in **Appendix B**. Future lifecycle cost estimates for each of the operating scenarios are included in **Appendix C**. Responses to the U.S. Environmental Protection Agency's comments on the *CS-10 Optimization Modeling - Phase II Results Presentation* at the 21 March 2013 Technical Update meeting are included in **Appendix D**.

2.0 BACKGROUND

The primary sources of contamination in the CS-10 plume are the Unit Training Equipment Site (UTES) and Boeing Michigan Aerospace Research Center (BOMARC) facility, where fuel supplies were stored and maintenance operations were conducted (AFCEC 2013b). The CS-10 source area (Figure 1) is referred to as the CS-10/Fuel Spill-24 source area site. Numerous other sources of contamination are also assumed to have contributed to the CS-10 plume (AFCEE 2008a). The contaminants of concern (COCs) for the CS-10 plume are TCE and tetrachloroethene (PCE). The CS-10 plume boundary is defined as the extent of groundwater containing TCE and/or PCE at concentrations above the Maximum Contaminant Level (MCL) of 5 micrograms per liter (µg/L) for each of these two contaminants.

The CS-10 plume no longer extends to the UTES/BOMARC source area. The main body of the CS-10 plume extends from approximately 1,500 feet [ft] downgradient of the UTES/BOMARC area to the northwestern shoreline of Ashumet Pond (Figure 1). The leading edge of the CS-10 plume underflows Ashumet Pond as three distinct lobes: the Northern lobe, the North Central lobe, and the Southern lobe. The CS-10 plume is approximately 3.6 miles long and 1.3 miles wide (Figure 1).

2.1 CS-10 REMEDIAL SYSTEM

Three treatment systems were designed to remediate the CS-10 plume: (1) the CS-10 SR extraction, treatment, and reinjection system, which includes the southern trench extraction well; (2) the CS-10 IP extraction, treatment, and infiltration system; and (3) the Northern lobe (i.e., the northernmost leading edge lobe) extraction well. The CS-10 plume and the location of the three treatment systems are presented in Figure 1.

Performance monitoring data collected under the CS-10 System Performance and Ecological Impact Monitoring (SPEIM)/Long Term Monitoring (LTM) program indicated the potential for optimization of the IP extraction wells but additional data were needed to evaluate optimized operational scenarios (Figure 2). In addition, TCE

concentrations exceeding the MCL of 5 µg/L were detected in offline SR extraction well 03EW2177. Based on a review of these data, a data gap investigation was completed at CS-10 to: (1) address data gaps associated with the nature and extent of contamination in the CS-10 IP area (north of the southern trench and 03EW2109) and the CS-10 SR area (in the vicinity of 03EW2176 and 03EW2177), (2) update the CS-10 TCE and PCE plume shells, (3) update the CS-10 groundwater flow model to more accurately represent hydrogeologic conditions at CS-10, and (4) predict future contaminant migration under current CS-10 remedial system operating conditions using the updated groundwater model and plume shells. The results of this data gap investigation were presented in the *Final CS-10 2012 Data Gap Investigation Technical Memorandum* which was submitted in January 2013 (AFCEC 2013c).

2.2 REGULATORY STATUS AND RESTORATION TIMEFRAME ESTIMATES

The final remedy for the CS-10 plume was determined in the *Final Record of Decision for Chemical Spill-10 Groundwater* (AFCEE 2009) which was signed in August 2009. The remedial action objectives for the CS-10 groundwater plume as presented in the Record of Decision (ROD) (AFCEE 2009) and modified in an Explanation of Significant Differences (AFCEE 2011) are as follows:

- Prevent residential exposure to CS-10 groundwater with TCE concentrations greater than the MCL of 5 µg/L.
- Prevent residential exposure to CS-10 groundwater with PCE concentrations greater than the MCL of 5 µg/L.
- Restore usable groundwaters to their beneficial uses wherever practicable, within a time frame that is reasonable given the particular circumstances of the site.

The selected remedy for CS-10 groundwater provides for continued active treatment of the CS-10 plume using the existing IP and SR remedial systems with a new extraction well (03EW2112) and a new reinjection well (03RI2112) southeast of the southern infiltration trench (**Figure 1**). The new extraction and reinjection wells specified as part of the final remedy wellfield configuration have been installed and came online in February 2009 (AFCEE 2010). The 2007 groundwater flow model and 2007 TCE plume shell were used to evaluate alternatives in the feasibility study (AFCEE 2008b) and

Alternative 10 was the selected alternative presented in the CS-10 ROD (AFCEE 2009). The groundwater modeling results for Alternative 10 operating conditions, which were presented in the CS-10 ROD, predicted that system shutdown would occur by approximately 2055 and aquifer restoration would be achieved by approximately 2094 (AFCEE 2009). As discussed in the following section, the 2007 CS-10 model and plume shell have been updated as the result of data gap investigation activities which has led to a revised understanding of the CS-10 conceptual site model (CSM). As such, optimization of the remedial system is needed to achieve the remedial system performance expectations for the selected remedy.

2.3 DATA GAP INVESTIGATION SUMMARY

Data gap investigation activities conducted between 2008 and 2012 led to an update in the CS-10 CSM. Changes to the CSM included a more thorough understanding of the nature and extent of contamination in the IP area, particularly in the area of CS-10 IP extraction wells 03EW2102, 03EW2103, 03EW2104, and 03EW2107 and to the west and east of the former CS-10 plume boundary. The CS-10 2012 plume boundary has been extended to encompass recently delineated contamination located outside the previous plume boundary (Figure 3) and these new data were used to update the 2007 TCE plume shell (AFCEC 2013c). The volume of TCE contamination in the CS-10 2012 TCE plume shell, based on the 2012 characterization, is 6,042 million gallons, which is approximately thirty-six percent greater than the volume of the 2007 plume shell that was used to support remedy selection. In addition to the increase in the extent of TCE contamination in the CS-10 plume, the data gap investigation identified higher TCE concentrations within the plume boundary that were not characterized at the time of remedy selection in 2009. Figure 4 presents a comparison of the 2007 and 2012 TCE plume shells and illustrates the difference in the TCE concentration ranges and distribution of contaminant mass before and after the data gap investigation in the main body (north of Ashumet Pond) of the CS-10 plume. There are 2,270 pounds (lbs) of dissolved phase TCE mass in the 2012 TCE plume shell, which is approximately 103 percent more mass than what was identified at the time of remedy selection using the 2007 TCE plume shell. The highest concentration in the 2007 TCE plume shell was 450

μg/L at 03MW1024D and the highest concentration in the 2012 TCE plume shell was 3,880 μg/L at rotosonic boring 03MW1069A.

Significant updates were made to the 2007 groundwater flow model to more accurately represent hydrogeologic conditions including groundwater flow at CS-10 (AFCEC 2013c). In the 2012 groundwater flow model the overall transmissivity of the simulated aquifer was reduced, particularly deeper in the aquifer. Past contaminant transport simulations show high concentration areas of the plume dissipating relatively quickly which was not considered realistic when compared to monitoring data. This may have been because many of the newly delineated fine sand lenses (with lower hydraulic conductivities) were not represented in the 2007 model. These lower hydraulic conductivity units slow down advective flow and plume migration as well as the simulated effects of hydrodynamic dispersion.

The 2012 CS-10 groundwater flow model and the updated 2012 CS-10 TCE plume shell were used to generate an animation of the contaminant transport migration of the CS-10 TCE plume under current (2012 Scenario 01) operating conditions. Although there are significant increases in the mass and volume of the updated 2012 TCE plume shell, transport modeling predicts that most of the TCE contamination will be contained under current operating conditions (2012 Scenario 01). The most notable area of TCE contamination that is not captured is located in the western area of the plume and is predicted to migrate to the west and south of extraction well 03EW2107 but does not migrate off base at concentrations above the MCL. Groundwater modeling results indicate that the newly defined eastern lobe of contamination (located near Generals Boulevard) will be contained in the future at SR under current system operating conditions, but modeling suggests this remedial strategy would prolong the operation of the SR remedial system up to 25 years (i.e., from 2030 to 2055) based on the current understanding of contaminant distribution in this area. Contamination located in the vicinity of extraction wells 03EW2102, 03EW2104, and 03EW2107 persists the longest and dictates the aquifer restoration timeframe under current operating conditions (i.e., beyond 2113). TCE concentrations in this area remain above the MCL after the last extraction well is taken out of operation (estimated to be 2065) but the contamination is

located deep in the aquifer and essentially attenuates in place to concentrations below the MCL over time without continued migration. An animation presenting the transport modeling results under current (2012 Scenario 01) operating conditions is included in **Appendix A**.

3.0 REMEDIAL SYSTEM OPTIMIZATION APPROACH

The updated 2012 CS-10 groundwater flow model and 2012 TCE plume shell were used to evaluate optimized operating scenarios for the CS-10 IP and CS-10 SR remedial systems. A two-phased approach was utilized for the optimization modeling evaluation. Revisions to the current infrastructure (i.e., revisions to extraction and reinjection/infiltration flow rates and effective extraction well screen settings) were evaluated initially during Phase I optimization modeling. The path forward for Phase I optimization modeling is documented in the *CS-10 2012 Remedial System Optimization Workplan Project Note, Phase I Approach* (AFCEE 2013), and Phase I modeling results were presented at the 28 November 2012 Technical Update meeting. Scenarios that simulate additional infrastructure (i.e., new extraction wells) were evaluated during the Phase II modeling effort. The plan for the Phase II modeling effort was initially presented at the 28 November 2012 Technical Update meeting and potential locations for the simulation of additional extraction wells were identified (**Figure 5**). The path forward for Phase II optimization modeling is documented in the *CS-10 2012 Remedial System Optimization Workplan Project Note, Phase II Approach* (AFCEC 2013a) and Phase II modeling results were presented at the 21 March 2013 Technical Update meeting.

3.1 PHASE I SCENARIOS

Modeling results from four optimized scenarios were evaluated. Similar to previous optimization modeling efforts, a manual iterative approach was used to select the optimal flow rates for each extraction well and for the infiltration trenches based on the results of capture zone analysis followed by many contaminant transport model simulations. The screened intervals at selected extraction wells were also optimized to focus the extraction stress where the contamination was located.

One optimization, the screen revision at 03EW2104, was implemented in October 2012 (AFCEE 2012). As presented in the *Final CS-10 2012 Data Gap Investigation Technical Memorandum* (AFCEC 2013c), capture of newly defined contamination located deeper in

the aquifer in the vicinity of 03EW2104 would be increased by modifying the effective screened interval at 03EW2104. The regulatory agencies concurred with this optimization (AFCEE 2012) and the packer was removed from the bottom of the extraction well screen at 03EW2104 (effective screen interval of 10 to -100 ft mean sea level [msl]) and was repositioned so that the top 90 ft of the extraction well screen is blocked (effective screened interval of -80 to -136 ft msl). This operating scenario is identified as CS-10 2012 Scenario 02. Revising the effective screen interval at 03EW2104 was evaluated in the optimized scenarios but this revision is not included in the CS-10 2012 Scenario 01 operating condition which is known as the "current operating scenario" in this report.

Universal changes to the SR and the IP remedial systems in each of the four scenarios evaluated under the Phase I optimization modeling effort are summarized in **Table 1** and included the following:

- Screen revision at 03EW2173
- Increased flow rates at 03EW2173 and 03EW2174,
- Decreased flow rates at 03EW2176 and 03EW2177,
- Screen revision at 03EW2102, 03EW2104, 03EW2107, and 03EW2109,
- Increased flow rate at 03EW2103,
- Decreased flow rates at 03EW2110 and 03EW2111, and
- Redistribution of flow to the southern and southwest infiltration trenches.

In addition to the universal changes, each of the four scenarios evaluated under Phase I are identified by varying flow rates at CS-10 IP extraction wells 03EW2102, 03EW2104, and 03EW2107 as follows:

Scenario	**Flow Rate (gpm)**		
	03EW2102	**03EW2104**	**03EW2107**
1	**460**	**275**	**150**
2	**425**	**425**	**150**
3	**650**	**275**	**60**
4	**650**	**425**	**150**

gpm = gallons per minute

The flow rates and screen settings for all of the CS-10 extraction wells, reinjection wells, and infiltration trenches for Alternative 10, current and optimized operating conditions are included in **Table 2**.

3.2 PHASE II SCENARIOS

The Phase II scenarios included simulation of a new deep screened extraction well in the 03EW2102/03EW2104 area (03EW2113) and/or a new extraction well in the eastern IP lobe (03EW2114) (**Figure 5**). Modeling results from three optimized scenarios were evaluated:

- Scenario 5 – new deep screened IP extraction well (03EW2113)
- Scenario 6 – new eastern IP extraction well (03EW2114)
- Scenario 7 – two new extraction wells (03EW2113 and 03EW2114)

In addition to the new extraction well(s), the benefits identified during the Phase I modeling evaluation were retained (e.g., the universal revisions to flow rates and effective screen settings). In addition to the universal revisions, flow rates at CS-10 IP extraction wells 03EW2102, 03EW2103, 03EW2104, and 03EW2107 also varied as follows:

Scenario	Flow Rate (gpm)					
	03EW2102	03EW2103	03EW2104	03EW2107	03EW2113	03EW2114
5	450	300	275	100	375	0
6	650	375	275	150	0	125
7	450	300	275	100	375	125

Higher flow rates were needed at 03EW2102, 03EW2103, and 03EW2107 under Scenario 6 because this scenario did not include the new deep extraction well located in the 03EW2102/03EW2104 area (03EW2113) and the operation of the new eastern IP extraction well (03EW2114) did not improve hydraulic capture in this area. Flow rates at 03EW2102, 03EW2103, 03EW2104, and 03EW2107 and at newly installed extraction

well 03EW2113 were consistent under both Scenario 5 and Scenario 7. For the transport animations it was assumed that the new extraction wells would not be operational for two years (2013 and 2014) and higher flow rates would be used at 03EW2102, 03EW2103, and 03EW2107 during the first two years under Scenario 5 and Scenario 7 (**Table 2**).

Although the 2007 groundwater flow model and 2007 TCE plume shell were used to evaluate alternatives in the ROD (AFCEE 2009), metrics presented in the ROD were compared to the Phase I and Phase II optimized scenario metrics (that were modeled using the 2012 CS-10 model and plume shell) which allowed assessment of remedial performance and included the following model-predicted metrics:

- aquifer restoration timeframe,
- remedial system shutdown year,
- mass removed at system shutdown,
- TCE plume mass and volume (at concentrations above the MCL) located outside the model-predicted capture zone at the initial time step of the simulation, and
- TCE plume mass and volume (at concentrations above the MCL) located outside the model-predicted capture zone at system shutdown year.

4.0 REMEDIAL SYSTEM OPTIMIZATION RESULTS

This section presents the remedial system optimization results and implementation and future lifecycle cost estimates for the optimized scenarios. Transport modeling animations are included in **Appendix A**, proposed pump and motor requirements for the optimized scenarios are included in **Appendix B**, and future lifecycle cost estimates are included in **Appendix C**. A detailed description of the recalibration of the CS-10 groundwater flow model and the updated 2012 TCE plume shell is included in the *Final CS-10 2012 Data Gap Investigation Technical Memorandum* (AFCEC 2013c).

4.1 MODEL SETUP AND TECHNICAL APPROACH

The updated 2012 CS-10 plume model and updated 2012 TCE plume shell, were used to perform this modeling-based optimization using the simulation capabilities of the MODFLOW-Surfact© modeling code. Well files were developed for four potential optimized scenarios using the existing CS-10 remedial system infrastructure under the Phase I task and for three potential optimized scenarios simulating additional infrastructure (one or two new extraction wells) under the Phase II task. The simulated flow rates and screen intervals used for the Phase I and Phase II optimized scenarios are summarized in **Table 2**. The simulated flow rates and screen intervals for Alternative 10, the preferred operational scenario presented in the CS-10 ROD, and for the current operating scenario (2012 Scenario 01) are also included in **Table 2**. The preliminary locations for the two new extraction wells simulated in the Phase II optimized scenarios are shown in **Figure 5**. For these simulations it was assumed that influent water from proposed new extraction well 03EW2113, located near the 03EW2102/03EW2104 area, would be piped to the existing CS-10 IP treatment plant and influent water from simulated new extraction well 03EW2114, located on the eastern side of the CS-10 plume (eastern IP lobe), would be piped to a mobile treatment unit (MTU) with treated water discharged using a new infiltration trench.

4.1.1 Plume Shell Update

The CS-10 2012 TCE plume shell was constructed during the data gap investigation for the portion of the CS-10 plume located to the north of Ashumet Pond. The plume shell is a three-dimensional representation of the distribution of contamination in the aquifer and provides a convenient mechanism for visualizing plumes in three dimensions, as well as initializing the groundwater model for running contaminant transport simulations. The updated TCE plume shell, referred to as the 2012 plume shell, is documented in the *Final CS-10 2012 Data Gap Investigation Technical Memorandum* (AFCEC 2013c).

The 2012 TCE plume shell is an improved representation from the 2007 plume shell. Major revisions included: expansion of the plume footprint, improved delineation of high concentration areas in the interior of the plume, and improved delineation of the vertical extent of contamination, particularly deeper in the aquifer.

4.1.2 Model Update

The 2007 CS-10 groundwater flow model was updated and recalibrated with the extensive set of lithologic and water level data collected during the CS-10 data gap investigation. The new model version is identified as the 2012 CS-10 groundwater flow model and was documented in the *Final CS-10 2012 Data Gap Investigation Technical Memorandum* (AFCEC 2013c). The updated plume model is a MODFLOW-Surfact© finite difference model with 30 layers, 436 rows, and 246 columns.

Major revisions to the CS-10 model included: the addition of 25 fine-sand and silty-sand lenses in areas where CS-10 TCE contamination is located, a reduction in hydraulic conductivity values in these areas, ranging from 40 to 85 percent lower than represented in the 2007 model, and the overall transmissivity of the simulated aquifer was reduced, particularly deeper in the aquifer to better match observed field conditions which results in more accurately simulating the groundwater flow.

4.2 SIMULATED HYDRAULIC CAPTURE ZONES

Potential optimized scenarios were developed and evaluated by first comparing the steady state extent of hydraulic capture under their operating conditions to the three-dimensional depiction of the CS-10 2012 TCE plume shell. The goal was to improve hydraulic capture of the plume compared to the current operating condition (2012 Scenario 01) and to reduce aquifer restoration timeframe. This evaluation focused on the following areas for the CS-10 IP remedial system: the deep portion of the aquifer in the area of extraction wells 03EW2102 and 03EW2104, the newly delineated eastern IP lobe, and the western side of the plume in the area of 03EW2107 where contamination is predicted to migrate around the southwest infiltration trench. Optimization of the CS-10 SR remedial system was also evaluated with the goal of containing the newly delineated eastern SR lobe (located in the vicinity of SR extraction wells 03EW2176 and 03EW2177) and improving the efficiency of this extraction fence.

For the Phase I optimization effort, adjustments to extraction flow rates, reinjection flow rates, and effective extraction screen intervals were evaluated. Increasing plume capture in the vicinity of extraction wells 03EW2102, 03EW2104, and 03EW2107 was achieved by increasing the pumping rates at these three extraction wells and focusing the extraction stress deeper in the aquifer by packering off the shallower portions of these extraction well screens. Revising the reinjection scenario by increasing flow to the southwest infiltration trench also helped to redirect migration of contamination to the eastern portion of the southwest trench toward extraction well 03EW2103. Packering off the shallow portion of 03EW2173 and revising flow rates in 03EW2173, 03EW2174, 03EW2176, and 03EW2177 improved the efficiency of the SR extraction fence and maintained capture.

For the Phase II optimization effort, increasing plume capture deep in the aquifer in the vicinity of extraction wells 03EW2102, 03EW2104, and 03EW2107 and/or decreasing the restoration timeframe for the new eastern IP lobe was achieved by simulating one or two new extraction wells to expand the extent of hydraulic capture and improve remedial performance over what can be achieved with the existing infrastructure. Simulated new

extraction well 03EW2113 is positioned in an area where monitoring data indicate there is TCE contamination at concentrations well above the MCL and to intercept deep contamination that is outside the capture zone of upgradient extraction wells 03EW2102 and 03EW2104. The position of simulated new extraction well 03EW2113 was adjusted further to reduce the simulated aquifer restoration timeframe in the area south of extraction wells 03EW2102 and 03EW2104 and west of extraction well 03EW2103 where contamination is most persistent.

Simulated new extraction well 03EW2114 was positioned in an area of the eastern IP lobe where monitoring data indicate there is TCE at concentrations over 100 µg/L. This location also would allow capture of contamination located further upgradient in the area of monitoring well 03MW2116A where higher concentrations (greater than 500 µg/L) have been detected (AFCEC 2013c). Monitoring and data gap investigation data indicate that this eastern IP lobe is relatively heterogeneous, not vertically and laterally extensive, and relatively difficult to delineate. Therefore, the simulated new extraction well (03EW2114) was positioned to be downgradient from but relatively close to the known high concentration area in this lobe. It is noted that characterization activities are ongoing in this area and the understanding of the extent of contamination will continue to evolve. If active treatment is pursued in this area through the installation of a new extraction well, the final position, flow rate and screened interval of that well should be based on the most current understanding of the nature and extent of contamination at that time.

Delineation of the steady-state extent of hydraulic capture by the CS-10 extraction wells was accomplished by particle tracking simulations in which one particle was initiated in each model cell in the area of the extraction wells. Particles that were placed in cells that are within the capture zones migrated to the extraction wells and were captured. Particles starting in cells outside the capture zones discharged to other exit points within the model. The capture zones were then illustrated by three-dimensional (3D) visualization software, which created bounding isosurfaces between the captured and uncaptured portions of the modeled aquifer.

Comparing the steady-state composite 3D capture zones for the optimized scenarios to the starting TCE concentrations in the model enabled generation of the CS-10 TCE plume hydraulic capture statistics that are presented in **Table 3**. The table shows initial dissolved TCE mass and plume volume estimates for plume concentrations greater than or equal to the TCE MCL that are outside of the steady-state composite capture zone for each scenario. The estimates for Alternative 10 and for the current operating condition scenario (2012 Scenario 01) are presented for comparison purposes. It should be noted that the Alternative 10 scenario capture statistics were generated using the 2007 groundwater flow model and the 2007 version of the TCE plume shell that were used to support remedy selection in 2009. The 2007 version of the TCE plume shell had approximately 49 percent of the mass and 75 percent of the volume above the TCE MCL that is present in the 2012 TCE plume shell version.

The capture statistics presented in **Table 3** indicate that optimized Scenarios 4 through 7 have the best simulated hydraulic capture percentages and exceed the capture performance of the Alternative 10 and current operating condition scenarios using these metrics as a means of comparison. Scenarios 4 through 7 had the best capture statistics with 2.0 to 2.2 percent of the initial dissolved TCE mass and 5.8 to 6.4 percent of the initial plume volume greater than or equal to the MCL located outside of the simulated composite capture zone. In comparison, the current operating condition scenario had 20.9 percent of the initial dissolved TCE mass and 27.3 percent of the initial plume volume greater than or equal to the MCL located outside of the simulated composite capture zone and Alternative 10, using the 2007 TCE plume shell and the 2007 groundwater model, had 4.9 percent of the initial dissolved TCE mass and 7.5 percent of the initial plume volume greater than or equal to the MCL located outside of the simulated composite capture zone.

A comparison of the steady-state composite extent of hydraulic capture to the 2012 TCE plume shell, for optimized Scenarios 4 and 7 and the current operating condition is shown on **Figure 6**. The composite capture zone for optimized Scenarios 4 and 7 operating conditions is more extensive in the western portion of the CS-10 plume in the vicinity of

extraction wells 03EW2104 and 03EW2107 when compared to the current operating condition. The improvements in capture are due to the increased pumping rates at extraction wells 03EW2103, 03EW2104, and 03EW2107, packering off of the shallow portion of the well screens at 03EW2104 and 03EW2107, and the addition of the new deep screened extraction well (03EW2113) for Scenario 7. There are several areas of the TCE plume that are outside of the optimized composite capture zone but TCE concentrations are low in these areas and the fate and transport modeling results indicate that contamination in these areas dissipates rapidly and concentrations drops below the MCL within the first few time steps of the simulation.

While the composite capture zones for optimized Scenarios 4 and 7 are similar in appearance, a significantly shorter aquifer restoration timeframe is achieved with Scenario 7 because contaminant mass located deep in the aquifer in the vicinity of extraction wells 03EW2102 and 03EW2104 is intercepted and captured by the simulated new extraction well 03EW2113 and shallower contamination is captured sooner with 03EW2113. Under Scenario 4, contaminant mass located shallower in the aquifer must migrate further south before it is either captured by extraction wells 03EW2103 and/or 03EW2111 or it dissipates to concentrations below the MCL. The contaminant concentrations located deeper in the aquifer slowly attenuate below the MCL as they migrate downgradient. Thus, the simulated extent of hydraulic capture is only one optimization evaluation tool and it should be assessed along with the results of fate and transport modeling to achieve a comprehensive understanding of the system optimization, particularly for a complex plume and remedial system such as at CS-10.

4.3 FATE AND TRANSPORT MODELING RESULTS

Fate and transport modeling provides a more thorough evaluation of model-predicted remedial system performance than can be obtained using only the groundwater flow model by assessing the extent of hydraulic capture alone. The updated 2012 CS-10 plume model and 2012 TCE plume shell (AFCEC 2013c) was used to perform fate and transport modeling for the optimized scenarios summarized in **Table 2**.

Contaminant migration is affected not only by the advective transport processes used to assess the simulated extent of hydraulic capture, but also by hydrodynamic dispersion, retardation, and degradation. Hydrodynamic dispersion refers to the spreading of a solute by the combined action of mechanical dispersion and molecular diffusion. Mechanical dispersion is caused by the variations in the magnitude and direction of velocity of groundwater as it flows around and between sand grains and other hydrodynamic discontinuities smaller than the model cells. Molecular diffusion occurs in response to contaminant concentration gradients, which cause the contaminant to move from regions of higher to lower concentration. In the Sagamore Lens aquifer that underlies upper Cape Cod, including the MMR, molecular diffusion is an insignificant contaminant transport process relative to mechanical dispersion, and is therefore omitted in the solute-transport modeling. Adsorption of contaminants to the aquifer matrix retards their rates of migration and is represented by the retardation factor. Degradation in groundwater refers to chemical changes in a contaminant due to microbial activity either in the presence of oxygen (aerobic) or in its absence (anaerobic), or to abiotic processes. The contaminant transport parameters used for this transport modeling are summarized in **Table 4** and remain consistent with those used in prior CS-10 modeling evaluations, including in support of remedy selection in 2009.

Steady-state contaminant transport simulations were run for a period of 100 years beginning in 2013. Optimized Scenarios 1 through 4 were run with constant pumping rates throughout the simulation. Optimized Scenarios 5 and 7 were run with an initial two-year period of interim pumping rates. The two-year period of interim pumping rates is intended to represent a realistic timeframe required to install the simulated new remedial system infrastructure that is being evaluated. Extraction wells 03EW2102 and 03EW2104 are turned off after 34 years to release contamination that is in a stagnation zone located just south of these two extraction wells so contamination can migrate to new extraction well 03EW2113. Optimized Scenario 6 was run with an initial two-year period of interim pumping rates, then a 98-year period with the optimized rates. A compact disk containing animations of the simulated migration of the CS-10 TCE plume under optimized Scenarios 1 through 7 and the current operating condition is provided as

Appendix A. The animations show three views: a plan view, a cross-sectional view looking north, and a cross-sectional view looking west. In each view, the maximum TCE concentration projected normal to the plane of view is depicted. The optimized scenario and current operating conditions are shown in each animation in a side-by-side comparison.

4.3.1 Simulation of Plume Migration

The animations show the simulated TCE plume migration (for concentrations above the MCL) for each of the optimized scenarios. Snap shots of the TCE plume extent for simulation years 2013 (initial time step), 2036, 2048, and 2055 are shown in Figures 7, 8, 9, and 10 for optimized Scenarios 4, 5, 6, and 7, respectively. Each figure shows a sequence of panels depicting the predicted extent of TCE contamination above the MCL at selected time steps in the simulations. In each view, the maximum concentration projected normal to the plane of view is depicted.

The current operating condition (2012 Scenario 01) is also included in the TCE plume migration figures for comparison purposes. By 2036, under current operating conditions, contamination in the 03EW2107 area has migrated around the southwest infiltration trench to the west and has migrated toward the southern infiltration trench to the east. Also, TCE concentrations have decreased below 300 µg/L in the CS-10 plume and TCE concentrations in all but a small area of the eastern IP lobe have decreased below 25 µg/L. By 2048 TCE concentrations have decreased below 100 µg/L, the contamination in the SR lobe has decreased below the MCL, but the eastern IP lobe has migrated to the SR extraction well fence. By 2055, contamination in the eastern IP lobe has nearly decreased below the MCL and the SR remedial system can be taken offline but a relatively large area where TCE concentrations are above the MCL remains deep in the aquifer between extraction wells 03EW2102, 03EW2104, and 03EW2107 to the north and extraction well 03EW2103 to the south.

Figure 7 compares the remedial performance of optimized Scenario 4 to the current operating condition. As shown in Figure 7, by 2036 there is only a small zone of TCE

concentrations in the IP area that are greater than 50 µg/L, contamination is not migrating west of 03EW2107, the leading edge of the SR lobe is located to the north of the SR fence and is attenuating in place, the eastern IP lobe has nearly migrated to the SR fence, and TCE concentrations in the eastern IP lobe are below 50 µg/L. By 2048, all TCE concentrations are less 50 µg/L, contamination in the IP area is located between 03EW2102 and 03EW2104 to the north and 03EW2103 to the south. The eastern IP lobe is being contained at the SR fence and TCE concentrations in the eastern IP lobe have decreased below 25 µg/L. By 2055 there is only a very small zone in the IP area with TCE concentrations greater than 25 µg/L; remaining IP contamination is located deep in the aquifer and is outside the capture zone of the IP extraction wells. The leading edge of the eastern lobe is located to the north of the SR fence where it attenuates to concentrations below the MCL.

Figure 8 compares the remedial performance of optimized Scenario 5 to the current operating condition. Contaminant migration is similar to the optimal Phase I scenario (optimized Scenario 4), with the following improvements in remediation with the addition of IP extraction well 03EW2113. By 2036 higher TCE concentrations in the IP area are being contained at new extraction well 03EW2113 and TCE contamination downgradient has broken up into separate smaller areas. By 2048, TCE concentrations have decreased below 25 µg/L and contamination located between new extraction well 03EW2113 and downgradient well 03EW2103 has essentially decreased below the MCL, leaving only a few small zones of TCE contamination in the IP area. By 2055, there are just a few very small areas of contamination with TCE concentrations above the MCL that are located deep in the aquifer. Concentrations in these remaining areas decrease below the MCL over a few years and aquifer restoration is achieved by approximately 2060 (**Appendix A**).

Figure 9 compares the remedial performance of optimized Scenario 6 to the current operating condition. The improvement in remediation of the Eastern IP lobe with addition of the eastern IP extraction well (03EW2114) compared to the other scenarios is illustrated. By 2036, TCE concentrations in the Eastern IP lobe have decreased below

25 μg/L and the plume extent is much smaller than in the other scenarios without this well and by 2048 concentration have decreased below the MCL and the leading edge attenuates below the MCL north of SR. Although there are also improvements in remediation of the IP area under this scenario compared to current operation conditions; it is not optimal compared to optimized Scenarios 4, 5, and 7 and a small zone of contamination still remains by 2113 (**Appendix A**).

Figure 10 compares the remedial performance of optimized Scenario 7 to the current operating condition. The addition of the two new extraction wells (03EW2113 and 03EW2114) in this scenario provide for a combination of the improvements in remediation of the IP area near 03EW2102/03EW2104 and in the Eastern IP area as described previously for Scenarios 5 and 7, respectively.

4.3.2 Remedial System Operation and Aquifer Restoration Timeframes

Three model-predicted performance metrics used to assess the optimized scenarios were developed with the regulatory agencies (AFCEE 2013 and AFCEC 2013a) and include: aquifer restoration timeframe, remedial system shutdown year, and mass removed at system shutdown. These three metrics are listed in **Table 5** for the two baseline scenarios (Alternative 10 and current condition) and optimized Scenarios 4, 5, 6, and 7.

The year for aquifer restoration was estimated from the animations for three areas of the TCE plume; the IP area, the area immediately upgradient of the SR extraction well fence, and the southern trench area (upgradient of extraction well 03EW2112). The restoration year was listed as the year the TCE concentrations dropped below the MCL in the respective area of the plume. The shortest overall model-predicted aquifer restoration timeframe estimate for the CS-10 plume was observed under optimized Scenario 7 operating conditions with an aquifer restoration year of 2056 (**Table 5**). This is a significant improvement over the estimate under current operating conditions (i.e., beyond 2113) and under Alternative 10 operating conditions (2094) as presented in the CS-10 ROD (AFCEE 2009) even though the 2007 TCE plume shell used for the

modeling of Alternative 10 at the time of the ROD was not an accurate representation of the extent of contamination at CS-10.

The system shut down year of 2055 for the IP remedial system did not vary under optimized Scenarios 4 through 7 and was also consistent with the estimate for the IP remedial system under Alternative 10 operating conditions (AFCEE 2009). Remedial system shutdown year for the IP remedial system and the SR remedial system was estimated from the animations and was determined when TCE contamination at concentrations above the MCL was no longer present in the immediate vicinity of the operating extraction wells or when continued operation of a well had little effect on remedial progress. Therefore, although the final shut down date for the IP system is the same for Scenarios 4 through 7, different configurations are assumed for each scenario throughout system operation. For example, in the case of Scenario 4, extraction wells 03EW2103 and 03EW2104 are assumed to be operational through 2055 and in Scenario 7 these two wells are taken out of operation in 2045 and only the new extraction well 03EW2113 is operational from 2045 to 2055. The 2055 estimate is an improvement over the estimate of 2065 for current operating conditions (**Table 5**).

The system shutdown year for the SR remedial system was significantly reduced from 2055 to 2035 with the addition of the new eastern IP extraction well (03EW2114) resulting in the SR system being taken out of operation after the SR lobe attenuated below the MCL instead of remaining online to remediate the eastern IP lobe when it reached the extraction fence. The 2035 estimate is comparable to the 2030 estimate for the SR remedial system under Alternative 10 operating conditions (AFCEE 2009).

The total TCE mass removed through system shutdown year was estimated by summing the mass removed by each individual extraction well. The operational timeframe for each individual extraction well was based on the animation and assumes the well would be shut down when TCE concentrations greater than the MCL were no longer located in the immediate vicinity of the extraction well. These TCE mass removal statistics only represent the predicted mass removal during the model simulations run for this optimization effort and do not include the mass removed since remedial system startup in

1999. The most mass (2,341 lbs) was removed under optimized Scenario 7 operating conditions, which is a significant improvement from the mass removed under current operating condition (2,030 lbs). The mass removal estimate of 1,191 lbs under Alternative 10 conditions is presented for completeness but cannot be used as a direct comparison since the 2007 TCE plume shell, which contained considerably less contaminant mass than the 2012 TCE plume shell, was used for Alternative 10 modeling.

Two more metrics used to evaluate the contaminant transport modeling results are the TCE dissolved mass and volume greater than the MCL remaining after 2055. The year 2055 is the estimated system shutdown year for the Alternative 10 scenario presented in the CS-10 ROD and is, therefore, a useful benchmark for comparison. These two metrics are listed in **Table 6** for the two baseline scenarios (Alternative 10 and current operating condition) and the optimized scenarios. Significantly less TCE plume mass and volume greater than the MCL remain after 2055 under optimized Scenarios 5 and 7 which are consistent with the reduced aquifer restoration timeframes for these two scenarios. The remedial system performance improvement is primarily due to the operation of simulated new extraction well 03EW2113.

4.3.3 TCE Plume Mass Removal Estimates

The model-predicted TCE cumulative mass removal estimates over time for each optimized scenario and for the current operating condition are presented in **Figure 11**. The mass removal estimates represent the total mass removal by the IP and SR remedial systems for each 100-year simulation. The most mass is removed under optimized Scenario 7 operating conditions, which is a significant improvement from current operating conditions, but is relatively consistent with mass removal estimates for Scenarios 4, 5, and 6. This is consistent with the summary presented in **Table 5**, but **Figure 11** illustrates that the majority of the TCE mass removal takes place in the first 20 years of the simulation.

In order to normalize the differences in mass and volume of TCE contamination in the 2007 and 2012 plume shells, the dissolved phase TCE mass and volume reduction are

presented as percentages of the initial TCE plume mass and volume above the MCL. Approximately 87 to 95 percent of the mass removal (**Figure 12**) and 60 to 74 percent of the volume reduction (**Figure 13**) takes place in the first 20 years of the simulation. Although Alternative 10 starts out with higher percentages of contaminant mass removal and plume volume reduction, optimized Scenario 7 out performs Alternative 10 for percent mass reduction after 27 years of operation and for percent plume volume reduction after 34 years.

4.4 WELL FIELD ANALYSIS AND LIFECYCLE COST ESTIMATES

A preliminary wellfield optimization analysis was performed using PIPE-FLO® Professional 7 computer modeling software in support of the Phase I optimization evaluation to determine the potential maximum achievable flow rates at selected existing extraction wells with the other extraction wells at current design flow rates and to determine the potential infrastructure requirements (i.e., new pumps and motors) needed to implement the scenarios. Note that in addition to pump and/or motor changes, a major overhaul of electrical service at extraction well 03EW2104 would also be required to achieve the higher flow rate used in optimized Scenarios 2 and 4 (**Table 7** and **Appendix B**). For the Phase II optimization evaluation, potential pipeline routes from new extraction wells to the IP treatment plant and/or to a newly installed MTU (**Figure 14**) were used to determine the pump and motor requirements at the newly installed extraction wells. The PIPE-FLO® software is capable of producing estimates for electricity consumption of extraction well pumps based on flow rates, well pump set depths, and piping system layout. The PIPE-FLO® software cannot be used to determine maximum achievable flow rates at the infiltration trenches so no limits were imposed on the infiltration capacity at the trenches.

Lifecycle Cost Estimation Methodology

In order to produce estimates of future lifecycle electrical costs for each scenario, models of the existing CS-10 remedial systems created in PIPE-FLO® Professional 7 piping system and fluid flow analysis software were modified to include infrastructure needed to

implement each of the respective optimized scenarios (i.e., new pumps and motors properly sized to deliver the optimized design flow rates, new extraction wells and associated pipelines, etc.). Well pump and motor selections for each scenario are included in **Appendix B**.

Starting with the PIPE-FLO® estimate of well pump power consumption required to produce the design flow rates under the current operating scenario (2012 Scenario 01) and the known cost of electricity used to operate the entire remedial system over the course of 2012, estimates of total electrical consumption (accounting for well pump motor consumption, treatment plant transfer pump operation, and all ancillary loads [i.e., programmable logic controllers, instrumentation, flow control valves, modems, resistive losses from wires, relays, switches, treatment plant lighting, etc.]) can be produced for each of the optimized scenarios. This is done by first modeling each scenario in PIPE-FLO® to produce an estimate of well pump electricity consumption required to produce the optimized design flow rates. Extraction well ancillary costs derived from the CS-10 2012 Scenario 01 operating condition (which are not expected to change considerably with varying extraction flow rates) are added to the estimates of well pump electricity costs to produce estimates of total annual extraction well operating costs at the optimized flow rates in the future (i.e., from 2012 forward). The operational timeframe for each individual extraction well was based on the animation; assuming the well would be taken out of operation when contaminant mass greater than the MCL was no longer located near the extraction well screened interval. These well pump electricity costs are then added to treatment plant electrical costs prorated by total system flow rate from actual CS-10 2012 Scenario 01 costs. An exception is the cost estimate for the remedial action for the Alternative 10 scenario, which was taken directly from the final CS-10 IRAR[1] to be consistent with the cost estimate previously presented for Alternative 10 (AFCEE 2010).

[1] Table "CS-10 Present Value SPEIM/O&M Costs", *Final Updated Interim Remedial Action Report for Chemical Spill-10 and Ashumet Valley Groundwater*.

Future annual costs for LTM for all scenarios were taken from the final CS-10 IRAR. To produce a total annual cost estimate for each scenario, annual estimated electrical costs produced by the method described previously were added to annual LTM costs, and to any implementation costs required to procure and install new equipment or facilities (i.e., resized pumps & motors, pipelines, well construction costs, MTU costs, etc.) needed to produce the optimized design flow rates. Total lifecycle cost estimates through the model-predicted date to reach aquifer restoration (i.e., TCE concentrations decline below the MCL throughout the plume) for each scenario are produced by adding all total annual costs. AFCEC's average 2012 electrical cost rate of $0.16 per kilowatt hour (kWh) was assumed in all cost estimates. This cost was not adjusted for future inflation to allow for comparison to the Alternative 10 cost estimate from the IRAR, which also was not adjusted for inflation.

Note that these future lifecycle cost estimates do not include all anticipated costs to run the remedial systems (such as labor and materials for operation and maintenance, the cost of granular activated carbon, data analysis and reporting), but do, however, provide a metric to compare the relative cost to implement one scenario against another based primarily on electrical usage, LTM costs, and implementation costs.

Comparison of Scenarios

Estimated lifecycle costs for optimized Scenarios 4 through 7 are provided in **Appendix C** and are summarized in **Table 8**. Scenarios 5 and 7 have the lowest estimated lifecycle costs. This is due to the fact that installation of new extraction well 03EW2113 is projected to result in reaching aquifer restoration 50 years earlier than Scenarios 4 and 6, which do not include this extraction well. The additional 50 years of LTM required under Scenarios 4 and 6 result in approximately $6.5 million in increased lifecycle costs, which more than offset the additional costs required to install the infrastructure associated with 03EW2113, and the resulting annual electrical costs to operate this extraction well.

The estimated lifecycle cost for Scenario 7 is marginally lower than that for Scenario 5; $50.4 million vs. $50.6 million, or a difference of approximately 0.4%. These two estimates can be considered to be equivalent. It is likely that operation of the MTU called for in Scenario 7 for treatment of water extracted by new eastern IP extraction well 03EW2114 will result in a higher level of effort by operations and maintenance staff due to its relative complexity with additional carbon exchanges, plant sampling, etc., compared to simply tying the 03EW2102/03EW2014 area extraction well (03EW2113) into the existing CS-10 IP treatment plant.

Sustainability Considerations

Given AFCEC's commitment to consider more sustainable, cost-efficient, low-impact engineering solutions, greenhouse gas (GHG) emissions were assessed as a sustainability metric. The predominant GHG emission from electricity generation is carbon dioxide (CO_2). Since the AFCEC-owned wind turbines annually produce more electricity than is used by the MMR IRP, any excess electricity produced by these turbines offsets electricity that would normally be generated in part by fossil fueled power plants. Scenarios that consume less electricity will result in less electricity required from traditional generation sources. For this reason, it is still accurate to assume that CO_2 emissions for each scenario are directly proportional to the total amount of electricity used over the lifecycle of the scenario, regardless of whether or not the electricity used by AFCEC is produced by the wind turbines or obtained from the common grid.

The estimated CO_2 emissions associated with system operation are directly proportional to the amount of electricity consumed through the projected system shutdown dates. These estimated values are shown in **Table 9**. It was assumed that 1.31 lbs of CO_2 were produced by the local electrical grid for each kWh of electricity used by the treatment systems[2]. Scenarios 6 and 7 have the lowest projected lifecycle CO_2 emissions of any of

[2] Air emissions are based on electricity produced by the average mix of generation sources in Massachusetts. CO_2 emission factor obtained from the following sources:
http://www.csgnetwork.com/elecpowerpolcalc.html
http://www.metrixcentral.com/EmissionsCalculator/Emissions%20Factors%202004.pdf

the proposed optimized scenarios (approximately 96 tons) due to their lower projected electricity consumption. However, in Scenario 6, LTM will be required for 50 years longer than in Scenario 7. While not included in the CO_2 emissions estimate in **Table 9**, the use of vehicles for an additional 50 years of LTM in Scenarios 6 and 4 may significantly increase the total lifecycle emissions associated with these scenarios. Therefore, Scenario 7 appears to have the lowest carbon footprint of all scenarios.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The updated 2012 CS-10 groundwater flow model and 2012 TCE plume shell were used to evaluate optimized operating scenarios for the CS-10 IP and SR remedial systems with the goal of improving plume capture and reducing aquifer restoration timeframe compared to current (2012 Scenario 01) operating conditions. Although the 2007 groundwater flow model and 2007 TCE plume shell were used to evaluate alternatives in the ROD (AFCEE 2009); metrics for plume mass, plume volume, remedial system operational timeframe, and aquifer restoration timeframe for the selected alternative in the ROD (Alternative 10) were compared to the optimized scenarios developed as part of this evaluation. Revisions to the current infrastructure were evaluated initially during Phase I optimization modeling and additional infrastructure scenarios were evaluated during the Phase II modeling effort. A summary of the conclusions from this optimization evaluation and recommendations for further actions at CS-10 are presented in the following sections.

5.1 PHASE I CONCLUSIONS

- Optimized Scenario 4 is the optimal Phase I scenario that utilizes the current infrastructure. Significant improvements in remedial system operation timeframe, aquifer restoration timeframe, and mass capture were achieved when compared to current (2012 Scenario 01) operating conditions.
- The remedial performance metrics achieved under optimized Scenario 4 were generally comparable to those presented in the ROD under Alternative 10 operating conditions at the time of remedy selection using the 2007 TCE plume shell and 2007 groundwater flow model.
  - The initial dissolved TCE plume mass and volume located outside the capture zone (at time zero) for optimized Scenario 4 in 2012 (44.4 lbs or 2.0 percent and 370 million gallons [Mgal] or 5.8 percent) is consistent with the initial TCE plume mass and volume located outside the capture zone for Alternative 10 (55.1 lbs or 4.9 percent and 359 Mgal or 7.5 percent) at the time of remedy selection in 2009.
  - Estimated year for remedial system shutdown for Alternative 10 and for optimized Scenario 4 is 2055.
  - The dissolved TCE plume mass and volume remaining after system shutdown under optimized Scenario 4 (16.7 lbs or 0.7 percent and 209 Mgal or 3.3 percent) is not significantly greater than the plume mass and volume remaining after

system shutdown under Alternative 10 (5.4 lbs or 0.5 percent and 51 Mgal or 1.1 percent) and maximum TCE concentrations remaining at 2055 are consistent (28 µg/L).

  – An estimate of 2106 for aquifer restoration under optimized Scenario 4 is within 12 years of the 2094 year estimate for Alternative 10.

- The increase in restoration timeframe under optimized Scenario 4, compared to the timeframe presented in the ROD under Alternative 10 operating conditions, is primarily related to the updated CSM. Specifically, the newly characterized contaminant mass located deeper in the aquifer and the lower hydraulic conductivity values in the updated conductivity field in this portion of the 2012 model result in a longer simulated restoration timeframe for Scenario 4 when compared to Alternative 10. Past contaminant transport simulations using the 2007 model showed high concentration areas of the plume dissipating relatively quickly which did not match the historic and recent monitoring data.

5.2 PHASE II CONCLUSIONS

- Aquifer restoration timeframe was significantly reduced under optimized Scenarios 5 (2060) and 7 (2056) compared to current operating conditions (>2112) and compared to Alternative 10 operating conditions using the 2007 TCE plume shell (2094). This improvement in aquifer restoration timeframe was expected because remaining mass located deep in the aquifer that was outside the capture zone of the current infrastructure is captured as a result of the simulated operation of the new deep screened IP extraction well (03EW2113).
- Installation of the eastern IP extraction well (03EW2114) in optimized Scenarios 6 and 7 reduced SR remedial system operation timeframe from 2055 to 2035. However, addition of this well alone (Scenario 6) did not reduce aquifer restoration timeframe. Contamination located deep in the aquifer in the 03EW2102/03EW2104 area persists the longest and dictates the aquifer restoration timeframe.
- Optimized Scenario 7, the most robust Phase II scenario with two new extraction wells, is the optimal Phase II scenario. Significant reductions in aquifer restoration timeframe and in SR remedial system operation timeframe were achieved with this scenario compared to the optimal Phase I scenario (optimized Scenario 4) and to the other Phase II scenarios.
- With the exception of aquifer restoration timeframe and SR remedial system operation timeframe, the other metrics evaluated for the Phase II scenarios were comparable to the optimal Phase I scenario, optimized Scenario 4.
  – For Scenarios 4 through 7, the estimated year for remedial system shutdown (when the last remaining operational extraction wells are taken offline) is 2055.
  – The initial dissolved TCE plume mass and volume located outside the capture zone (at time zero) for optimized Scenario 4 (44.4 lbs or 2.0 percent and 370 Mgal or 5.8 percent) is consistent with the initial TCE plume mass and

volume located outside the capture zone for the more robust Phase II optimized Scenario 7 (44.8 lbs or 2.0 percent and 392 Mgal or 6.2 percent).

  – Mass removal estimates were comparable under optimized Scenario 4 (2,337 lbs) and under the more robust Phase II optimized Scenario 7 (2,341 lbs).

- Scenarios 6 and 7 have the lowest projected lifecycle CO_2 emissions (approximately 96 tons) of any of the proposed optimized scenarios (Scenarios 4 through 7) due to their lower projected electricity consumption. However, in Scenario 6, LTM will be required for 50 years longer than in Scenario 7. The use of vehicles for an additional 50 years of LTM in Scenarios 6 and 4, which is not included in the CO_2 emissions estimates, may significantly increase the total lifecycle emissions associated with these scenarios. Therefore, Scenario 7 appears to have the lowest carbon footprint of all scenarios.
- Scenarios 5 and 7 have the lowest estimated future lifecycle costs of approximately $50.5 million. The addition of new extraction well 03EW2113 is predicted to shorten the aquifer restoration timeframe by up to 50 years when compared to Scenarios 4 and 6 (which do not include simulation of this extraction well). The additional 50 years of LTM required under Scenarios 4 and 6 result in approximately $6.5 million in increased lifecycle costs, which more than offsets the cost of installing and operating 03EW2113. The lifecycle cost estimate of $50.5 million for optimized Scenarios 5 and 7 is consistent with the cost estimate of $50.2 million for Alternative 10 which was developed at the time of remedy selection (AFCEE 2010).

5.3 RECOMMENDATIONS

Recommendations for further actions at the CS-10 IP and SR areas based on the results of this optimization evaluation are as follows:

- The objective of this optimization evaluation was to improve plume capture and to reduce aquifer restoration timeframe. The most significant improvement in plume capture and in reducing aquifer restoration timeframe was achieved with optimized Scenario 7. This scenario also reduced operation timeframe for the SR remedial system. Based on a comparison of the remedial performance metrics developed for this evaluation, Scenario 7 meets or exceeds the performance expectations for Alternative 10 operating conditions which was the basis for remedy selection. AFCEC has programmed funds and is developing plans to implement Scenario 7. A future Project Note that presents the wellfield design for Scenario 7 should be prepared for regulatory review and approval.
- Significant updates were made to the CS-10 CSM based on findings from the 2012 data gap investigation (AFCEC 2013c). Additional monitoring of the newly installed data gap wells is needed to determine if the contamination in high concentration areas upgradient of 03EW2102/03EW2104 and in the eastern IP lobe is persistent and to establish TCE concentration trends within the recently identified zones of contamination. Optimization of the current CS-10 SPEIM chemical monitoring

network is ongoing and the selection of wells evaluated will include the 86 newly installed monitoring wells. It is recommended that the results of this monitoring network optimization be presented at a Technical Update meeting and documented in a project note.

- Contamination in the eastern IP lobe is heterogeneous and is not laterally or vertically extensive and data gaps remain (AFCEC 2013c). Delineation of contamination in the eastern IP lobe area is currently ongoing and should be completed prior to developing the final well field design layout if active treatment (as simulated under Scenarios 6 and 7) is pursued for this area.
- The results of the ongoing eastern IP lobe investigation will be used to complete a focused update of the 2012 TCE plume shell. This 2013 TCE plume shell should be used with the 2012 groundwater flow model to determine the layout for the Scenario 7 wellfield design.
- Although PIPE-FLO® Professional 7 computer modeling software was used to determine the potential maximum achievable flow rates at IP and SR extraction wells, this software cannot be used to determine maximum achievable flow rates at the infiltration trenches. The results of field flow testing at the southwest infiltration trench indicated that the optimized reinjection flow rate assumed for the southwest infiltration trench under Scenario 7 (900 to 966 gpm) is close to the current capacity for this infiltration trench and is not likely sustainable for long term operation. Installation of a new IP reinjection well (03RI2113) to accommodate increased flow to the southwest infiltration trench should be considered since it would be a more reliable alternative than the extension and/or rehabilitation of the existing southwest infiltration trench. A new reinjection well (03RI2114) should also be considered as the means to return treated water from the MTU simulated under Scenario 7. The location, flow rate, and screen settings for these two proposed new reinjection wells would be determined during final well field design modeling.
- An Explanation of Significant Differences should be prepared to document the changes in the CS-10 CSM and how this updated understanding of the plume has changed the predicted outcome of the remedial action compared to expectations at the time of remedy selection in 2009. The implementation of Scenario 7 should also be documented in the Explanation of Significant Differences.

6.0 REFERENCES

Air Force Civil Engineer Center (AFCEC). 2013a (March). *CS-10 2012 Remedial System Optimization Workplan Project Note, Phase II Approach*. 437075-SPEIM-CS10-PRJNOT-002. Prepared by CH2M HILL for AFCEC/MMR, Installation Restoration Program, Otis Air National Guard Base, MA.

______. 2013b (March). *Chemical Spill-10 Groundwater Plume Conceptual Site Model.* 437075-SPEIM-CS10-CSM-001. Prepared by CH2M HILL for AFCEC/MMR, Installation Restoration Program, Otis Air National Guard Base, MA.

______. 2013c (January). *Final Chemical Spill-10 2012 Data Gap Investigation Technical Memorandum.* 437075-SPEIM-CS10-TECHMEMO-001. Prepared by CH2M HILL for AFCEC/MMR, Installation Restoration Program, Otis Air National Guard Base, MA.

Air Force Center for Engineering and the Environment (AFCEE). 2013 (January). *CS-10 2012 Remedial System Optimization Workplan Project Note, Phase I Approach*. 437075-SPEIM-CS10-PRJNOT-001. Prepared by CH2M HILL for AFCEE/MMR, Installation Restoration Program, Otis Air National Guard Base, MA.

______. 2012 (September). *CS-10 In-Plume 03EW2104 Modifications Project Note.* AFCEE/MMR, Installation Restoration Program, Otis Air National Guard Base, MA.

______. 2011 (September). *Final Explanation of Significant Differences for the Installation Restoration Program Groundwater Plumes at the Massachusetts Military Reservation.* 404929-SPEIM-MULTIPLE-RPT-001. Prepared by CH2M HILL for AFCEE/MMR, Installation Restoration Program, Otis Air National Guard Base, MA.

______. 2010 (August). *Final Updated Interim Remedial Action Report for Chemical Spill-10 and Ashumet Valley Groundwater Plumes*. Prepared by ECC for AFCEE/MMR, Installation Restoration Program, Otis Air National Guard Base, MA.

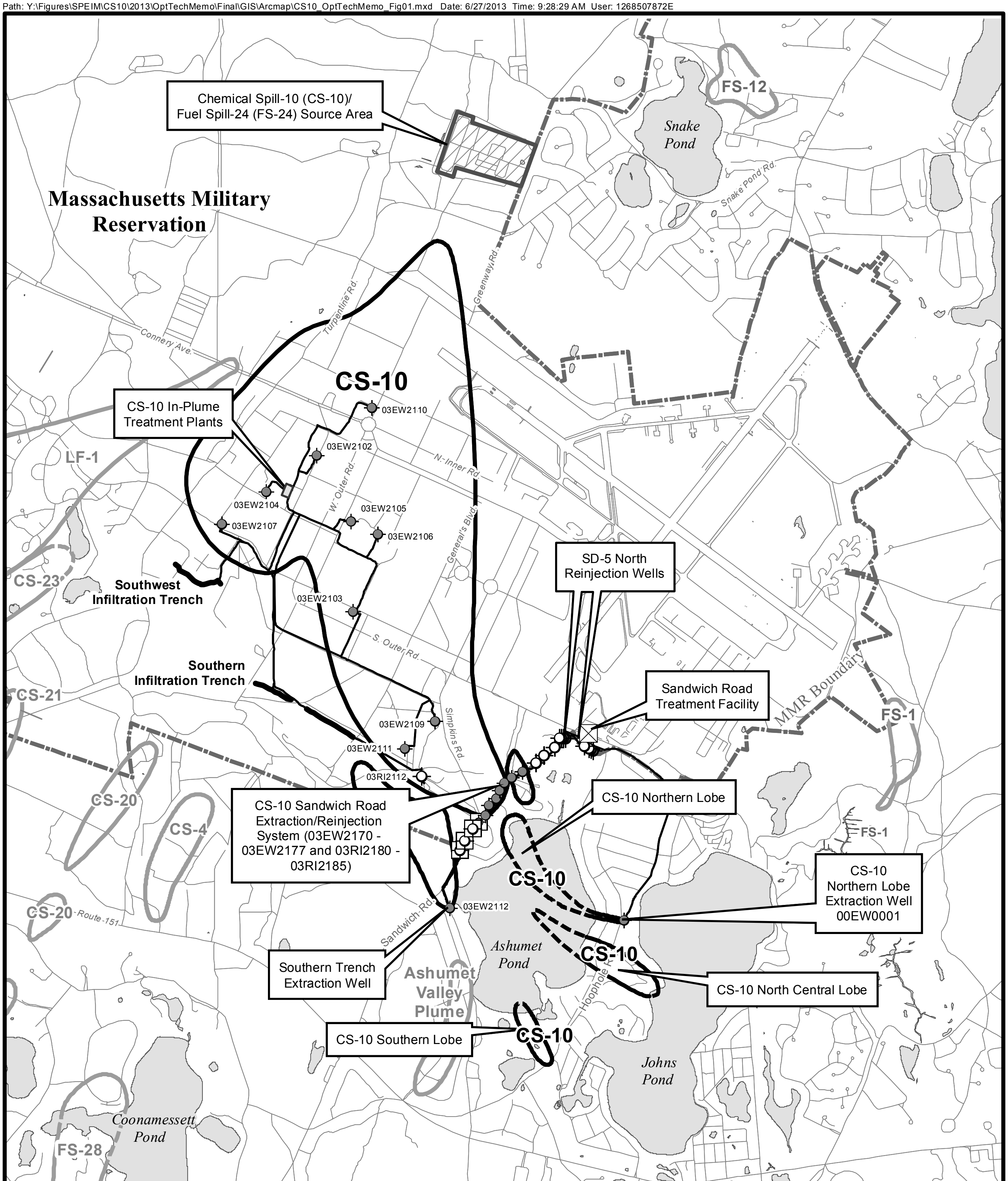
______. 2009 (August). *Final Record of Decision for Chemical Spill-10 Groundwater*. A4P-J23-35BC02VA-M26-0018. Prepared by Jacobs Engineering Group for AFCEE/MMR, Installation Restoration Program, Otis Air National Guard Base, MA.

_____. 2008a (September). *Final 3rd Five-Year Review, 2002-2007 Massachusetts Military Reservation (MMR) Superfund Site, Otis Air National Guard Base, MA* Prepared by ESC, Portage and CH2M HILL for AFCEE/MMR, Installation Restoration Program, Otis Air National Guard Base, MA.

______. 2008b (August). *Final Supplement to the Chemical Spill-10 Groundwater Feasibility Study Addendum.* A4P-J23-35BC02VA-M16-0025. Prepared by Jacobs Engineering Group for AFCEE/MMR, Installation Restoration Program, Otis Air National Guard Base, MA.

FIGURES

Path: Y:\Figures\SPEIM\CS10\2013\OptTechMemo\Final\GIS\Arcmap\CS10_OptTechMemo_Fig01.mxd Date: 6/27/2013 Time: 9:28:29 AM User: 1268507872E



Legend

- CS-10 Plume Boundary (Dashed Where Inferred)
- Other Plume Boundary (Dashed Where Inferred)
- Massachusetts Military Reservation Boundary
- Treatment System Piping
- Infiltration Trench
- Extraction Well (On)
- Extraction Well (Off)
- Reinjection Well (On)
- Reinjection Well (Off)
- Treatment Facility
- Primary Source Area

Data Source: AFCEC, January 2013, MMR-AFCEC Warehouse

N

0 1,700 3,400 Feet

FIGURE 1

CS-10 GROUNDWATER PLUME AND TREATMENT SYSTEMS

AFCEC - Massachusetts Military Reservation

Final CS-10 2013 Optimization Tech Memo

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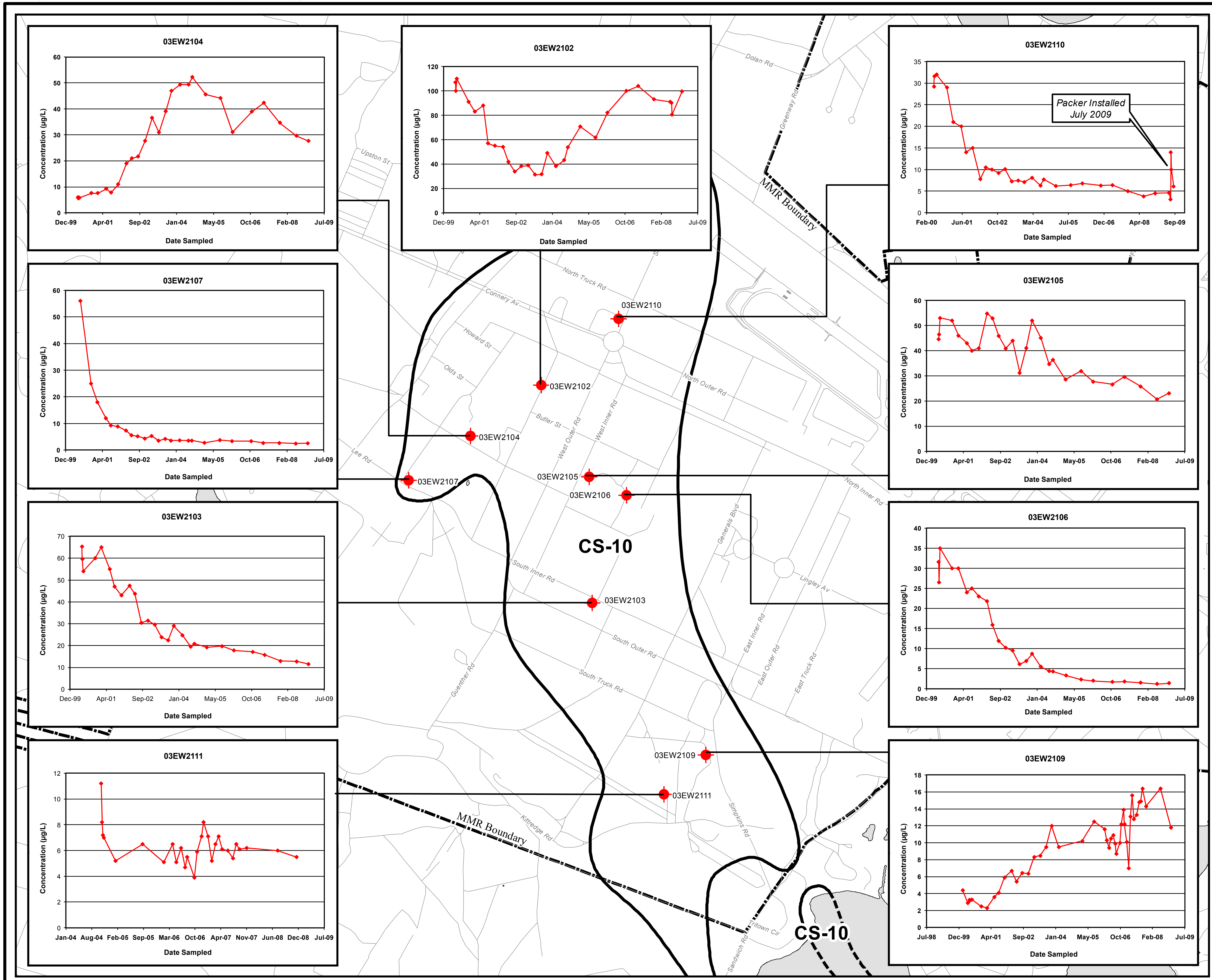

Legend

- Extraction Well
- Massachusetts Military Reservation Boundary
- 2007 CS-10 Plume Boundary (Dashed Where Inferred)
- TCE

0 820 1,640 Feet

Data Source: AFCEC, February 2010, MMR-AFCEC Data Warehouse
MMR Boundary from Massachusetts Air National Guard 2011

FIGURE 2

TCE CONCENTRATION TRENDS IN CS-10 IN-PLUME EXTRACTION WELLS

AFCEC - Massachusetts Military Reservation

Final CS-10 2013 Optimization Tech Memo

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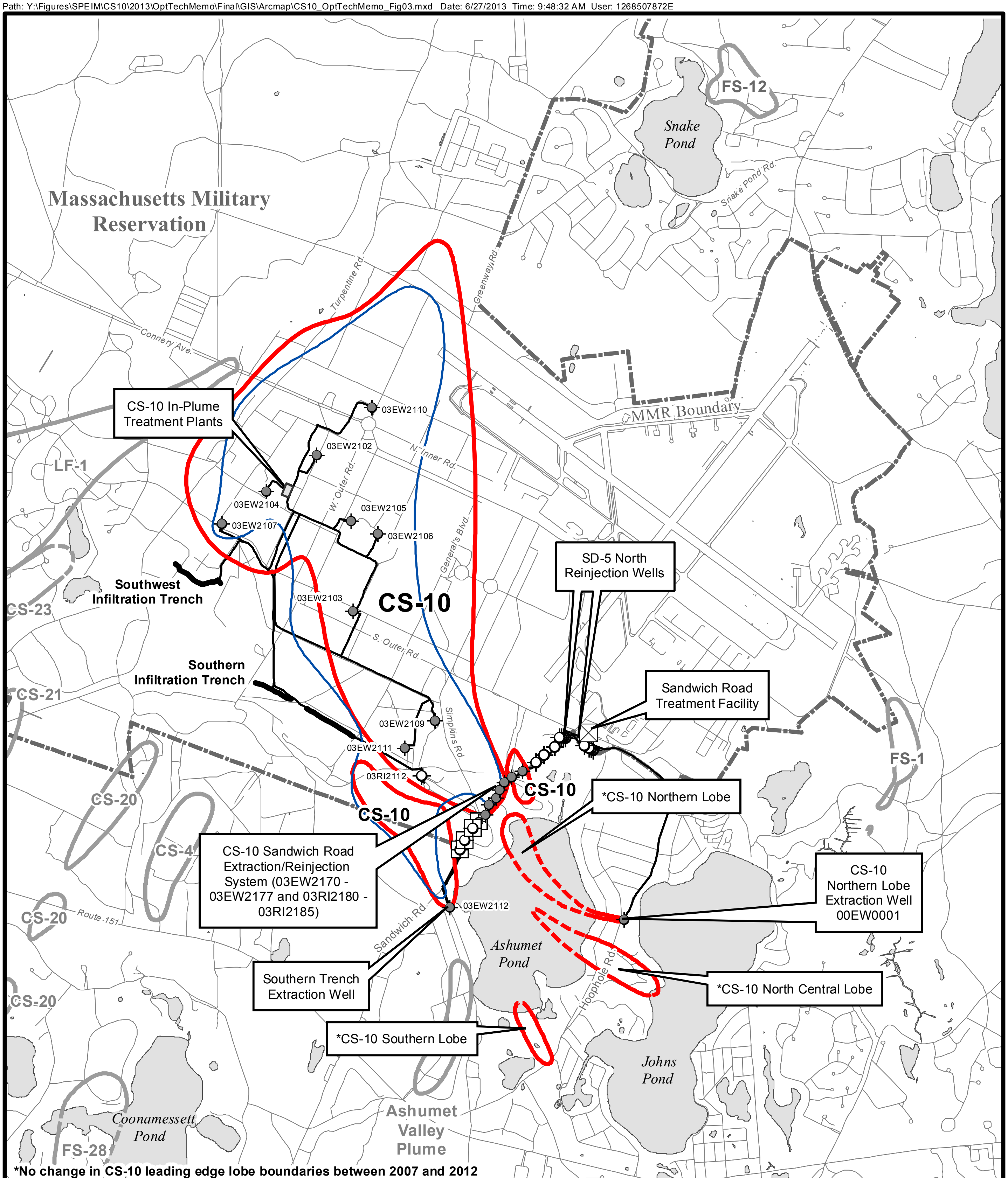

Legend

- 2012 CS-10 Plume Boundary (Dashed Where Inferred)
- 2007 CS-10 Plume Boundary (Dashed Where Inferred)
- Other Plume Boundary (Dashed Where Inferred)
- Massachusetts Military Reservation Boundary
- Treatment System Piping
- Infiltration Trench
- Extraction Well (On)
- Extraction Well (Off)
- Reinjection Well (On)
- Reinjection Well (Off)
- Treatment Facility

Data Source: AFCEC, February 2013, MMR-AFCEC Warehouse
MMR Boundary from Massachusetts Air National Guard 2011

N

0 1,700 3,400
Feet

FIGURE 3

COMPARISON OF CS-10 2007 AND 2012 PLUME BOUNDARIES
AFCEC - Massachusetts Military Reservation
Final CS-10 2013 Optimization Tech Memo

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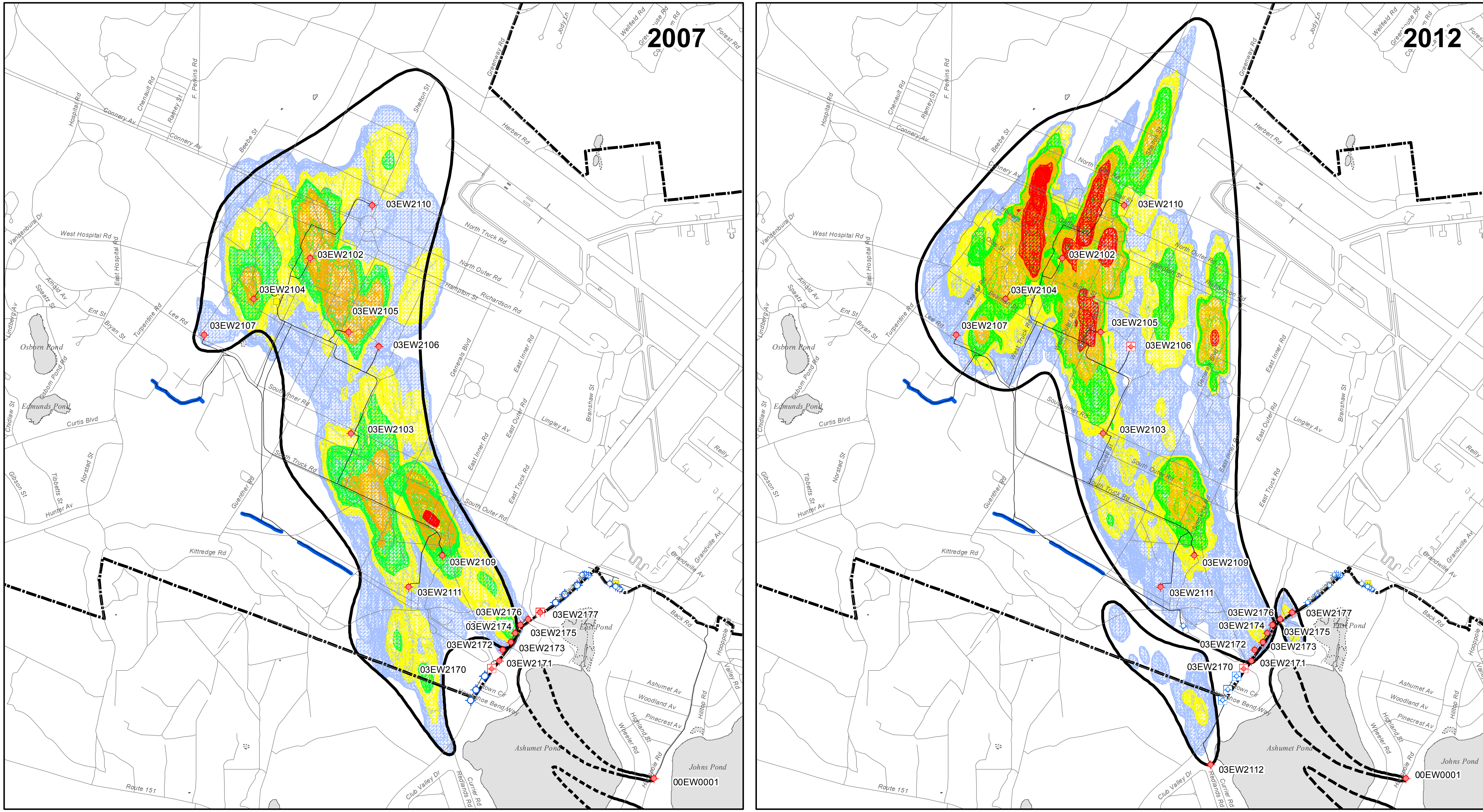

Legend

- Massachusetts Military Reservation Boundary
- Plume Boundary (Dashed Where Inferred)
- Infiltration Trench/Gallery
- Treatment System Pipeline
- Bog/Wetland
- Treatment Facility
- Extraction Well (On)
- Reinjection Well (On)
- Extraction Well (Off)
- Reinjection Well (Off)

TCE Plume Shell

- 5 ≤ TCE < 25 μg/L
- 25 ≤ TCE < 50 μg/L
- 50 ≤ TCE < 100 μg/L
- 100 ≤ TCE < 300 μg/L
- TCE ≥ 300 μg/L*

*Maximum TCE concentration in the 2007 TCE plume shell dataset is 450 μg/L at 03MW1024D
Maximum TCE concentration in the 2012 TCE plume shell dataset is 3880 μg/L at 03MW1069A

Data Source: AFCEC, MMR-AFCEC Data Warehouse
MMR Boundary from Massachusetts Air National Guard 2011

N

0 1,000 2,000
Feet

FIGURE 4

COMPARISON OF CS-10 2007 AND 2012 TCE PLUME SHELLS

AFCEC - Massachusetts Military Reservation

Final CS-10 2013 Optimization Tech Memo

CH2MHILL.

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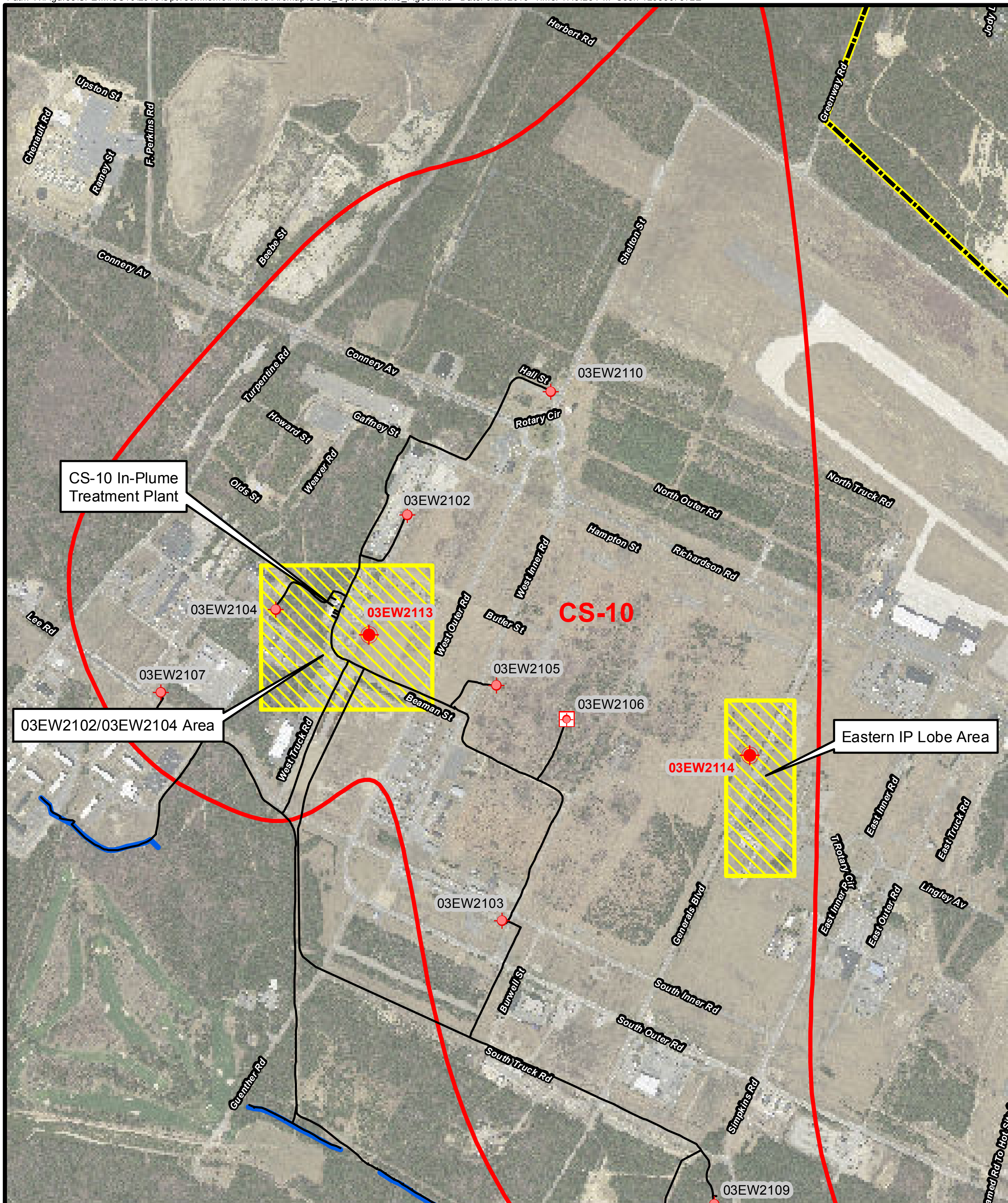


Legend

- Treatment System Pipeline
- Plume Boundary
- Infiltration Trench/Gallery
- Extraction Well (On)
- Extraction Well (Off)
- Proposed Extraction Well
- Massachusetts Military Reservation Boundary

Data Source: AFCEC, MMR-AFCEC Data Warehouse
MMR Boundary from Massachusetts Air National Guard 2011
2009 Aerial Photography from MassGIS

0 620 1,240 Feet

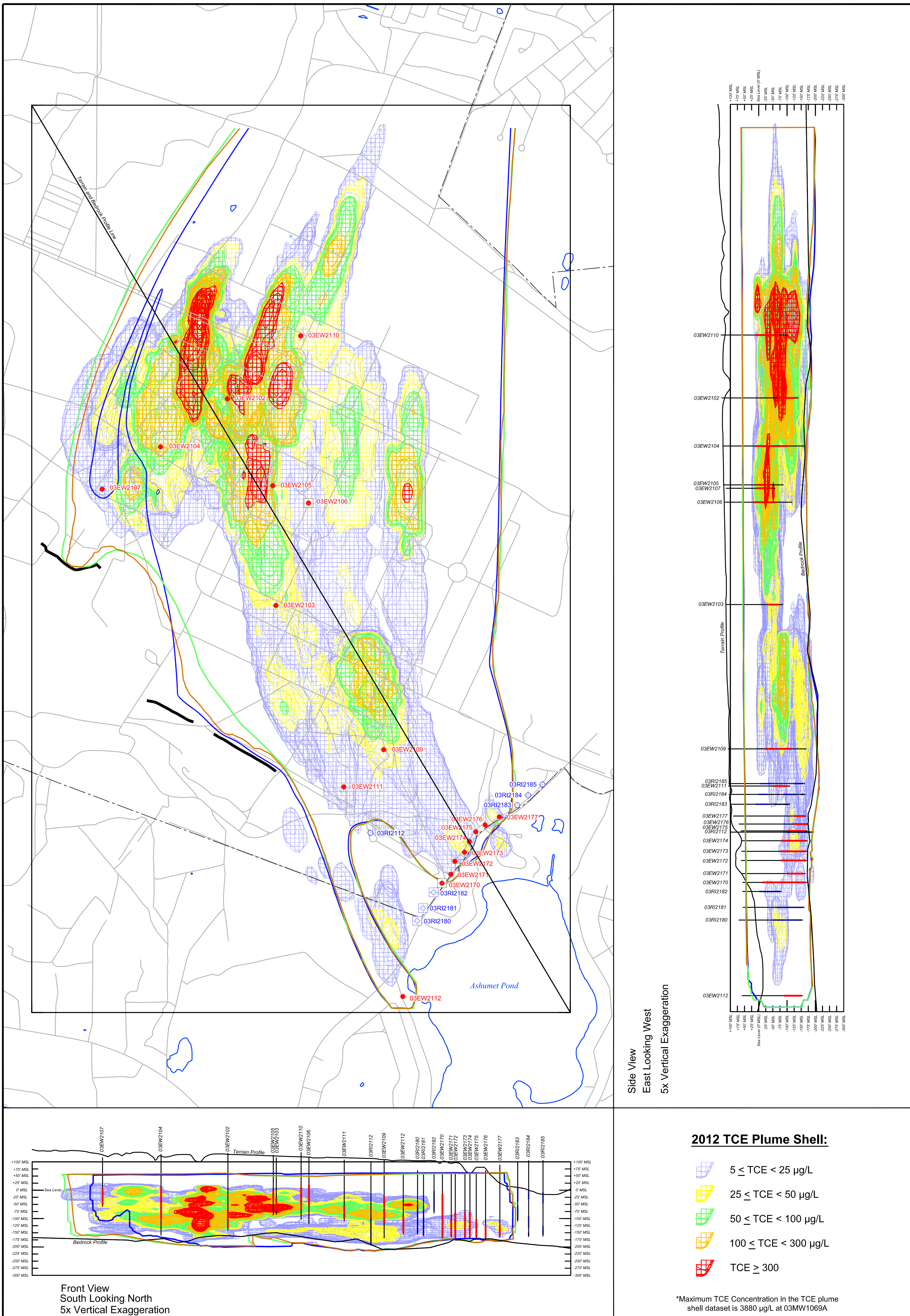
FIGURE 5

EXTRACTION WELL AREAS FOR PHASE II MODELING

AFCEC - Massachusetts Military Reservation

Final CS-10 2013 Optimization Tech Memo

CH2MHILL



Legend

- Extraction Well (On)
- Extraction Well (Off)
- Reinjection Well (On)
- Reinjection Well (Off)
- Infiltration Trench

Data Source: AFCEC, June 2012, MMR-AFCEC Data Warehouse

Extent of Model-Predicted Capture Zones

- Current Operating Conditions
- Scenario 4 Operating Conditions
- Scenario 7 Operating Conditions

0 1600 Feet

FIGURE 6

CS-10 2012 TCE PLUME SHELL AND MODEL-PREDICTED EXTENT OF CAPTURE ZONES

AFCEC - Massachusetts Military Reservation

Final CS-10 2013 Optimization Tech Memo

CH2MHILL.

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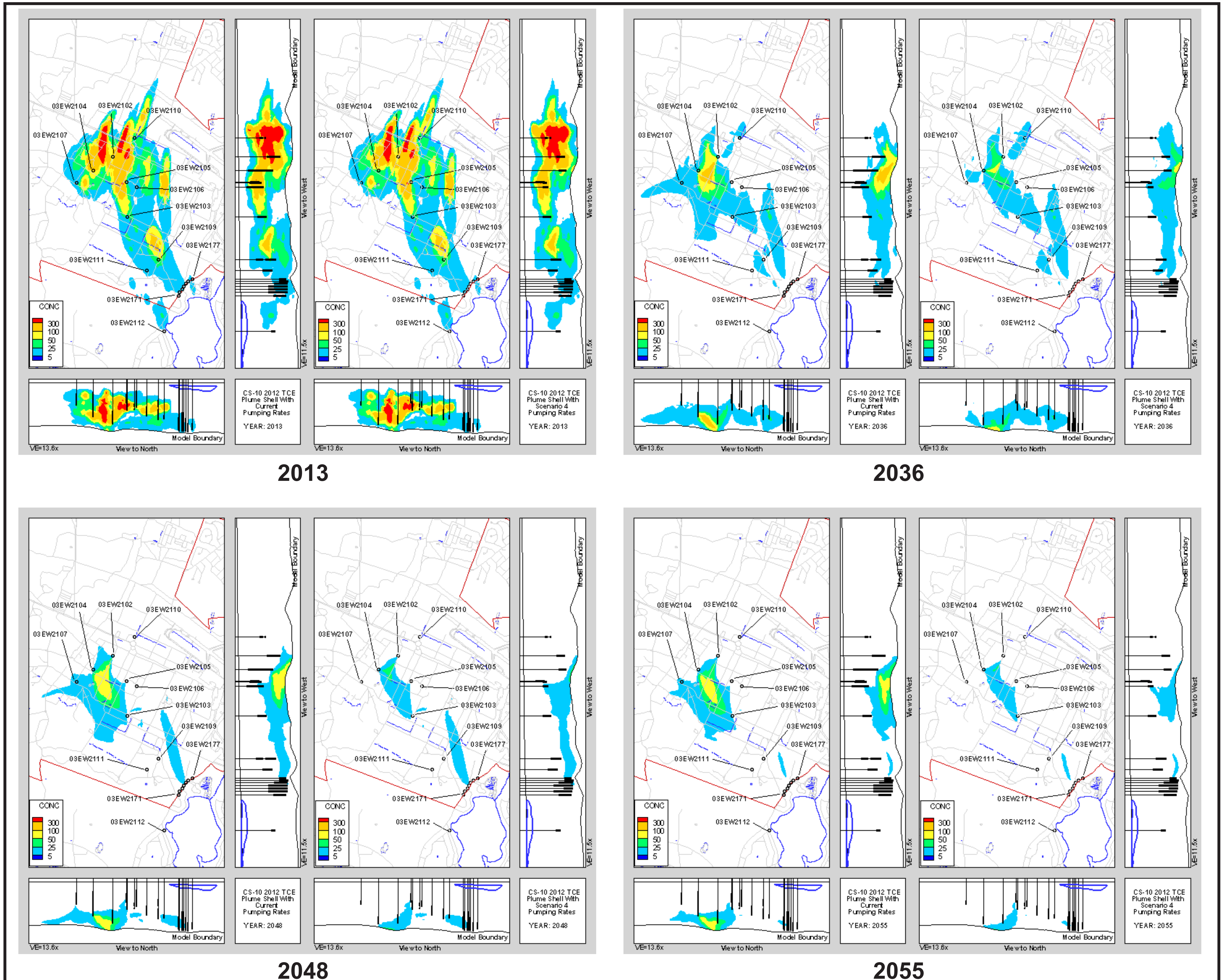


Legend

- 5 μg/L ≤ TCE < 25 μg/L
- 25 μg/L ≤ TCE < 50 μg/L
- 50 μg/L ≤ TCE < 100 μg/L
- 100 μg/L ≤ TCE < 300 μg/L
- 300 μg/L < TCE

Data Source: AFCEC, MMR-AFCEC Data Warehouse

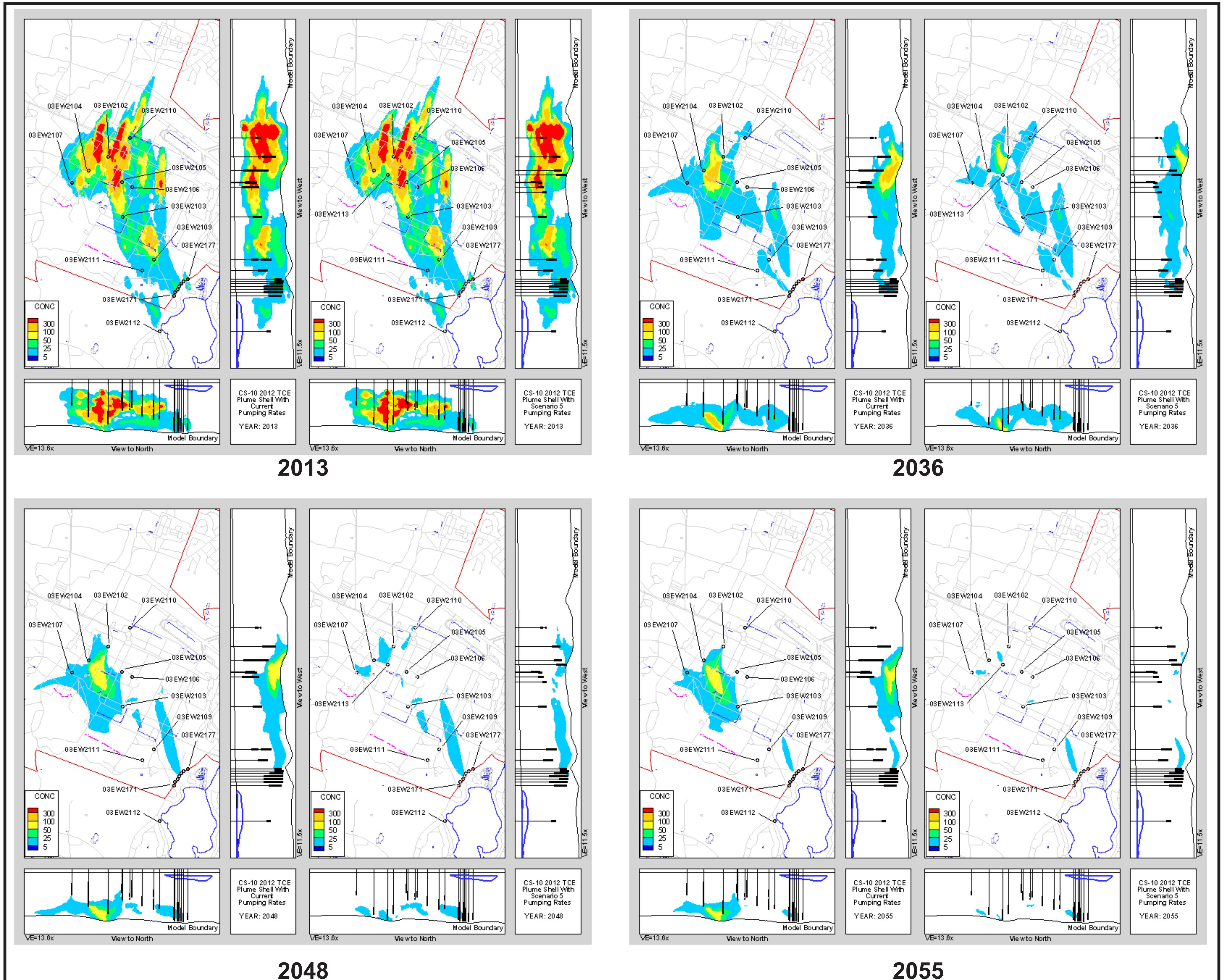
FIGURE 7

MODEL SIMULATED MIGRATION OF THE CS-10 TCE PLUME UNDER CURRENT OPERATING CONDITIONS AND OPTIMIZED SCENARIO 4

AFCEC - Massachusetts Military Reservation

Final CS-10 2013 Optimization Tech Memo

CH2MHILL



Legend

- 5 µg/L ≤ TCE < 25 µg/L
- 25 µg/L ≤ TCE < 50 µg/L
- 50 µg/L ≤ TCE < 100 µg/L
- 100 µg/L ≤ TCE < 300 µg/L
- 300 µg/L < TCE

Data Source: AFCEC, MMR-AFCEC Data Warehouse

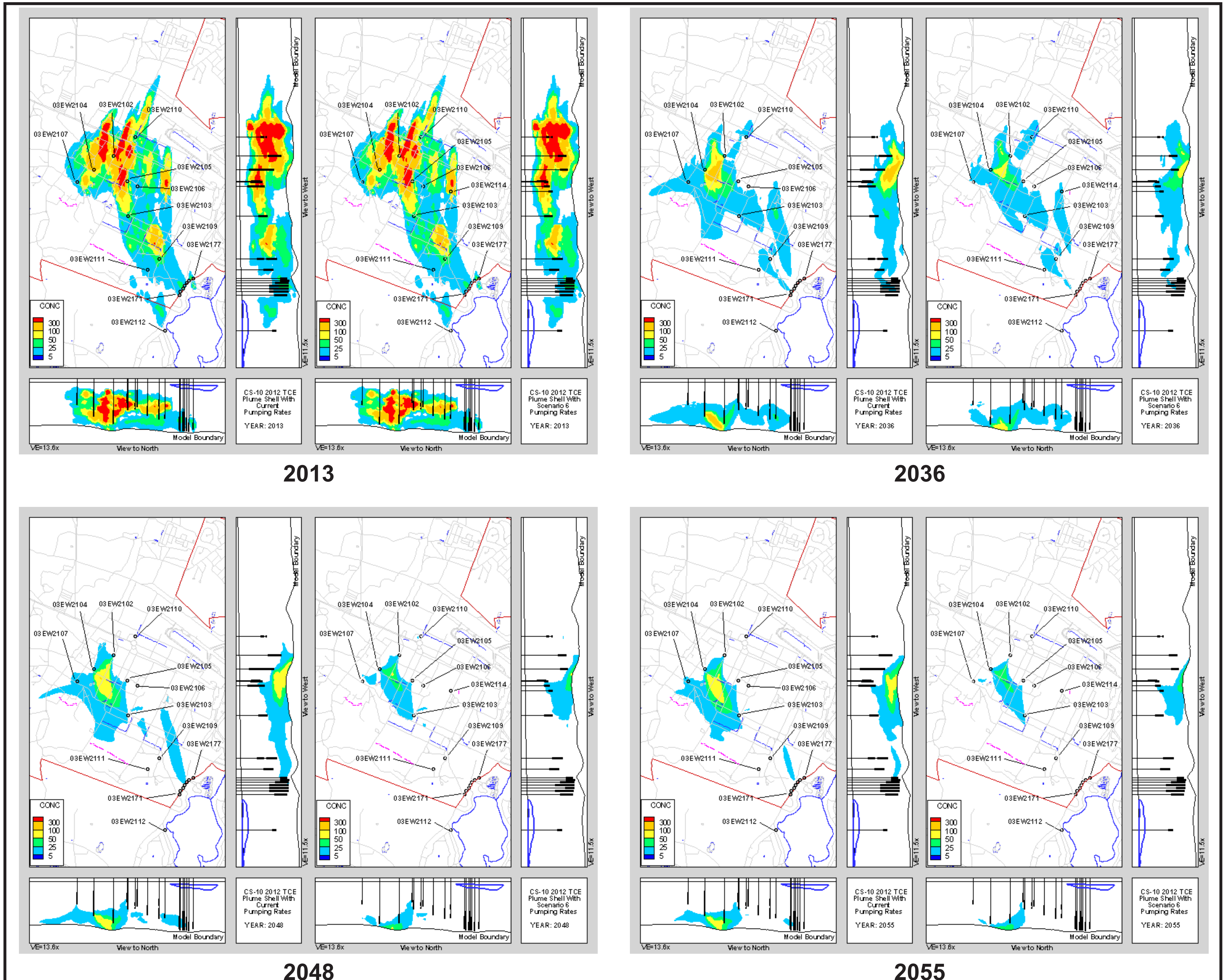
FIGURE 8

MODEL SIMULATED MIGRATION OF THE CS-10 TCE PLUME UNDER CURRENT OPERATING CONDITIONS AND OPTIMIZED SCENARIO 5

AFCEC - Massachusetts Military Reservation

Final CS-10 2013 Optimization Tech Memo

CH2MHILL



Legend

- 5 µg/L ≤ TCE < 25 µg/L
- 25 µg/L ≤ TCE < 50 µg/L
- 50 µg/L ≤ TCE < 100 µg/L
- 100 µg/L ≤ TCE < 300 µg/L
- 300 µg/L < TCE

Data Source: AFCEC, MMR-AFCEC Data Warehouse

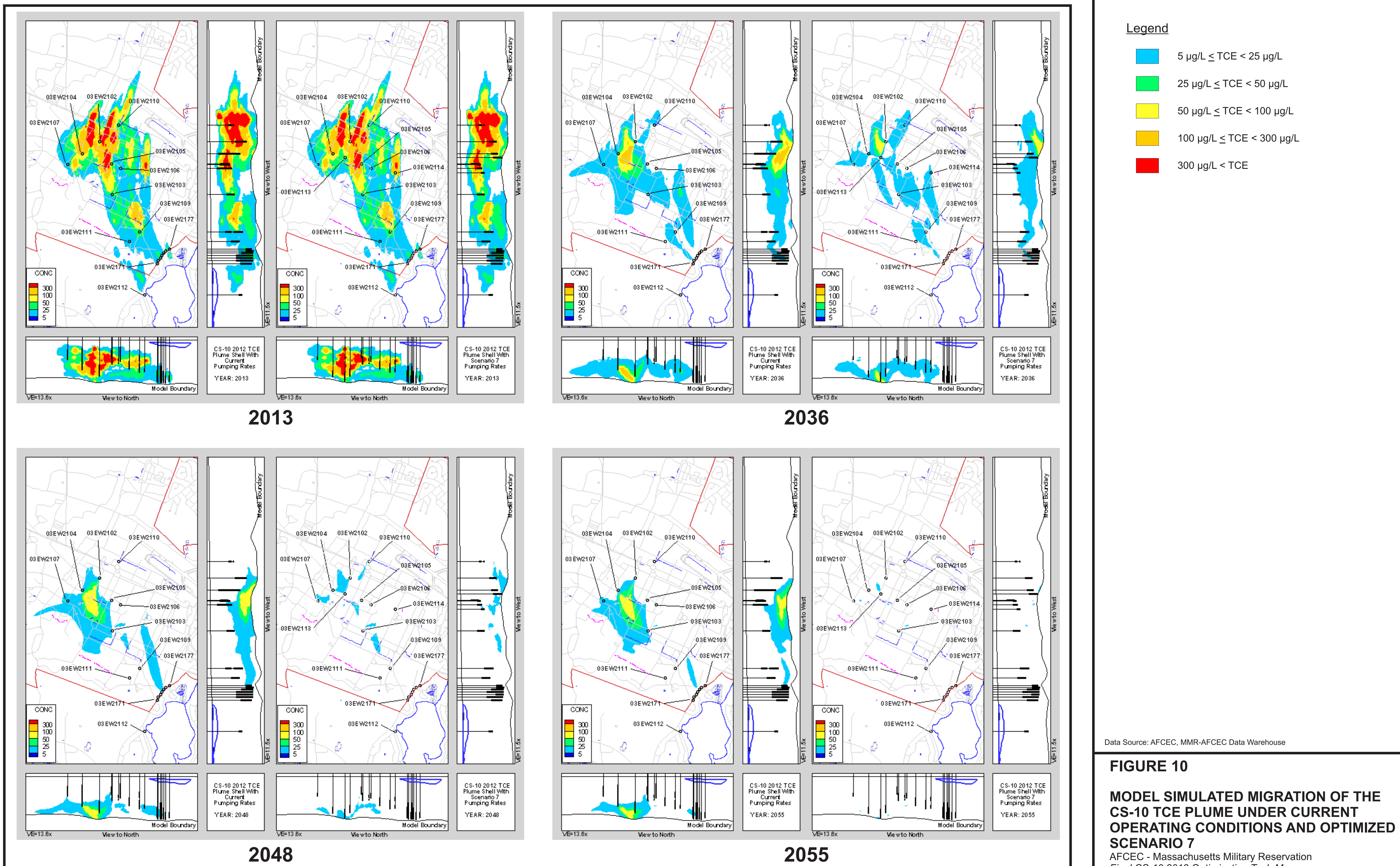
FIGURE 9

MODEL SIMULATED MIGRATION OF THE CS-10 TCE PLUME UNDER CURRENT OPERATING CONDITIONS AND OPTIMIZED SCENARIO 6

AFCEC - Massachusetts Military Reservation

Final CS-10 2013 Optimization Tech Memo

CH2MHILL



Data Source: AFCEC, MMR-AFCEC Data Warehouse

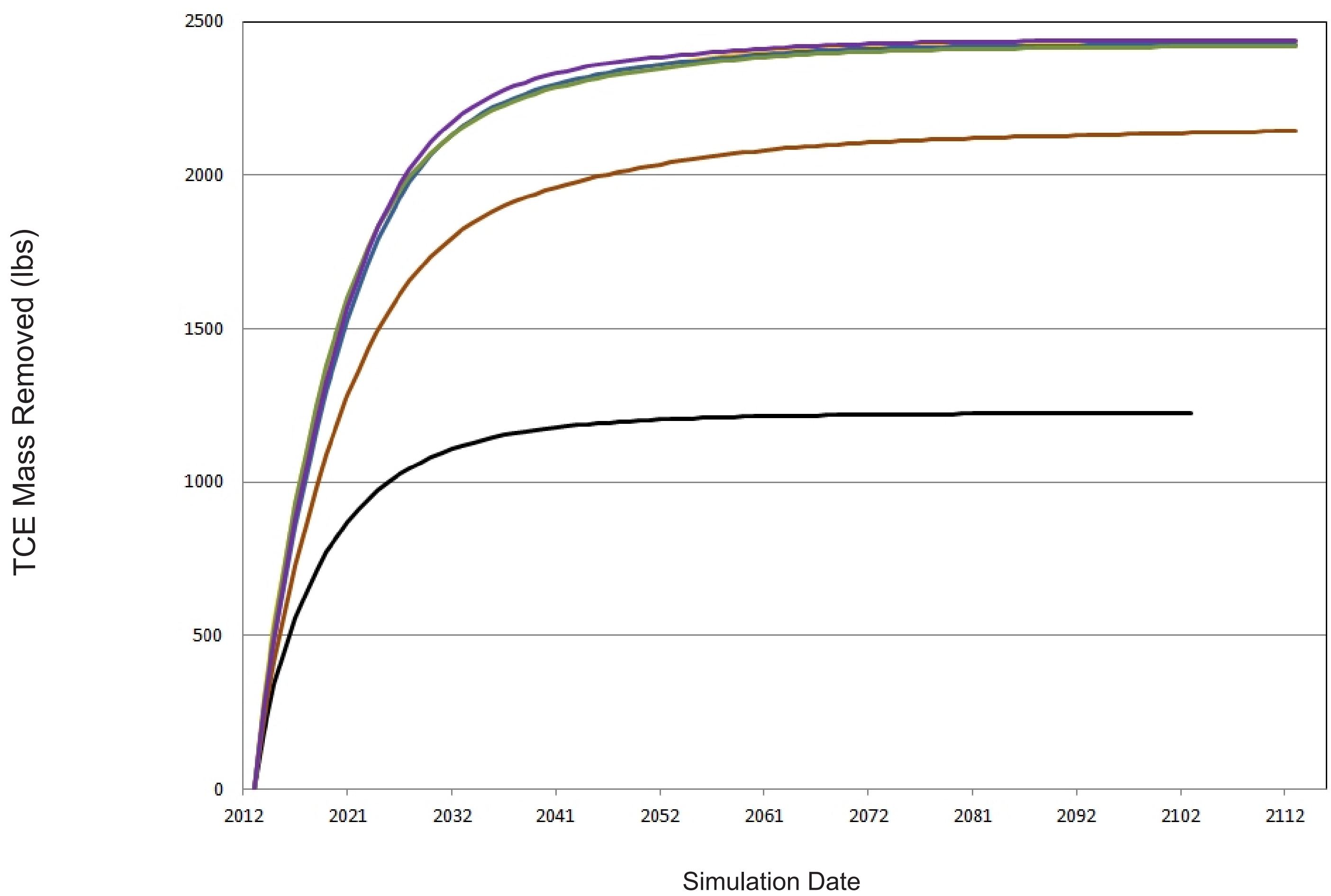
FIGURE 10

MODEL SIMULATED MIGRATION OF THE CS-10 TCE PLUME UNDER CURRENT OPERATING CONDITIONS AND OPTIMIZED SCENARIO 7

AFCEC - Massachusetts Military Reservation

Final CS-10 2013 Optimization Tech Memo

CH2MHILL



Legend

- Alternative 10 (2007 Model)
- Current
- Scenario 4
- Scenario 5
- Scenario 6
- Scenario 7

Data Source: AFCEC, MMR-AFCEC Data Warehouse

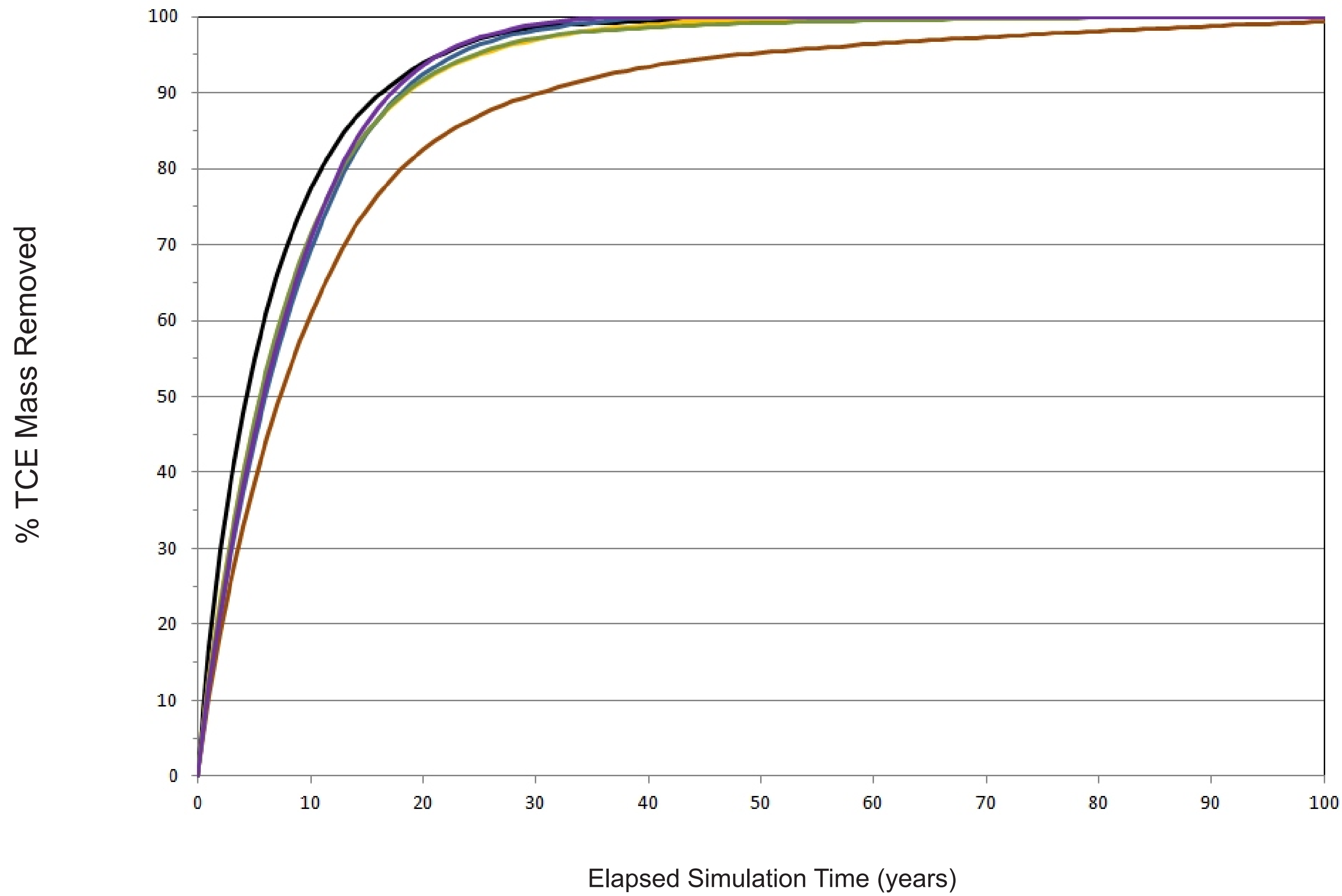
FIGURE 11

MODEL - PREDICTED CUMULATIVE TCE MASS REMOVED

AFCEC - Massachusetts Military Reservation

Final CS-10 2013 Optimization Tech Memo

CH2MHILL



Legend

Alternative 10 (2007 Model)
Current
Scenario 4
Scenario 5
Scenario 6
Scenario 7

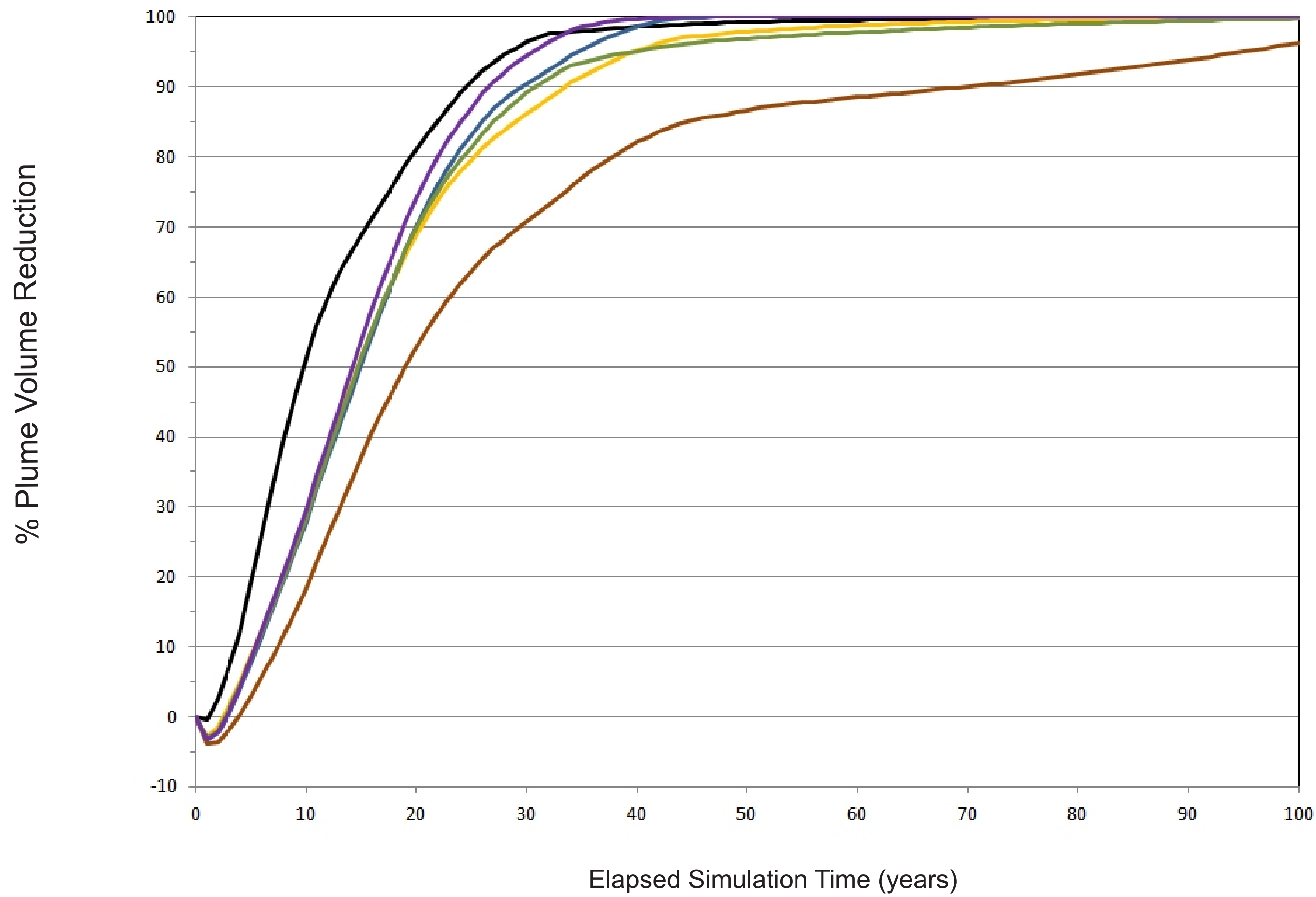
Data Source: AFCEC, MMR-AFCEC Data Warehouse

FIGURE 12

PERCENT TCE MASS REDUCTION

AFCEC - Massachusetts Military Reservation
Final CS-10 2013 Optimization Tech Memo

CH2MHILL



Legend

- Alternative 10 (2007 Model)
- Current
- Scenario 4
- Scenario 5
- Scenario 6
- Scenario 7

Data Source: AFCEC, MMR-AFCEC Data Warehouse

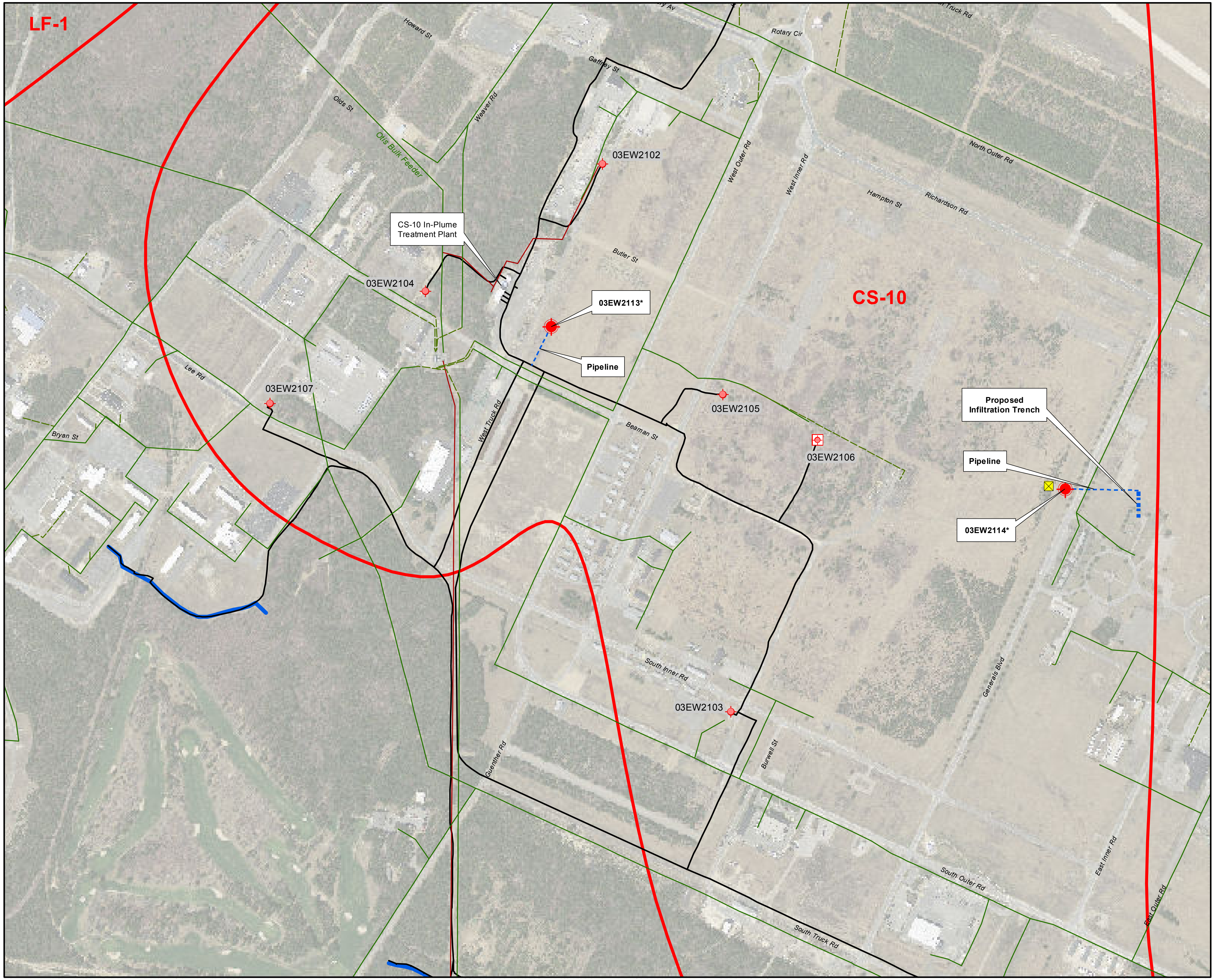
FIGURE 13

PERCENT TCE PLUME VOLUME REDUCTION

AFCEC - Massachusetts Military Reservation

Final CS-10 2013 Optimization Tech Memo

CH2MHILL



Legend

- Plume Boundary (Dashed Where Inferred)
- Treatment System Pipeline
- Treatment System Pipeline (Proposed)
- Base CE Electric Line (Above Ground)
- Base CE Electric Line (Below Ground)
- NSTAR Electric Line (Above Ground)
- NSTAR Electric Line (Below Ground)
- Infiltration Trench
- Proposed Infiltration Trench
- Extraction Well (On)
- Extraction Well (Off)
- Mobile Treatment Unit
- Proposed Extraction Well

*Note: Final locations to be determined based on wellfield design modeling

The bulk feeder is owned by the 102nd IW (Otis ANG Base) but the supplied electricity is metered by NSTAR

0 330 660
Feet

Data Source: AFCEC, MMR-AFCEC Data Warehouse
2009 Aerial Photography from MassGIS

FIGURE 14

CONCEPTUAL LAYOUT FOR OPTIMIZED SCENARIO 7

AFCEC - Massachusetts Military Reservation

Final CS-10 2013 Optimization Tech Memo

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TABLES

Table 1
Universal Revisions Under Phase I and Phase II Optimization Scenarios
Final CS-10 2013 Technical Memorandum: Focused Feasibility Study for Remedial System Optimization

Location	Alternative 10/ Current Screen Setting		Optimized Screen Setting		Pumping Rates (gpm)		
	Top Screen Elevation (ft msl)	Bottom Screen Elevation (ft msl)	Top Screen Elevation (ft msl)	Bottom Screen Elevation (ft msl)	Alternative 10 (Pumping Scenario in ROD)	Current Pumping Scenario (2012 Scenario 01)	Optimized Pumping Scenario
Sandwich Road System							
03EW2170	-100, -14	-164	-14	-164	-170	0	0
03EW2171	-101	-157	-101	-157	-75	-75	-75
03EW2172	-79	-163	-79	-163	-75	-75	-75
03EW2173	-79	-165	-125	-165	-100	-100	-110
03EW2174	-79	-163	-79	-163	-100	-100	-110
03EW2175	-103	-164	-103	-164	-60	-60	-60
03EW2176	-125	-167	-125	-167	0	-75	-40
03EW2177	-125	-159	-125	-159	0	-50	-60
03EW2112	-90	-150, -110	-90	-110	-290	-100	-100
Total SR Extraction (gpm)					**-870**	**-635**	**-630**
In-Plume System							
03EW2102	-70	-131	-90	-131	-460	-460	-x
03EW2103	-30	-70	-30	-70	-300	-300	-x
03EW2104	10	-100	-100	-136	-230	-230	-x
03EW2105	2	-40	2	-40	-450	-450	-450
03EW2106	18	-57	-30	-57	-80	0	0
03EW2107	6	-50	-30	-50	-50	-50	-x
03EW2109	-24	-114	-66	-114	-125	-125	-125
03EW2110	10, -40	-70	-40	-70	-250	-250	-100
03EW2111	-53	-98	-53	-98	-425	-425	-400
Total IP Extraction (gpm)					**-2370**	**-2290**	
Sandwich Road Reinjection							
03RI2180	-51	-151	-51	-151	0	0	0
03RI2181	-58	-158	-58	-158	0	0	0
03RI2182	-3	-73	-3	-73	0	0	0
03RI2183	11	-105	11	-105	120	40	120
03RI2184	-1	-160	-1	-160	162	156	162
03RI2185	-6	-156	-6	-156	163	108	163
Total SR Reinjection					**445**	**304**	**445**
Total In-Plume Reinjection/Infiltration							
Southern Infiltration Trench	56	48	56	48	1232	1232	782 - 1229
Southwest Infiltration Trench	58	53	58	53	758	678	801 - 1377
03RI2112	-100	-190	-100	-190	380	380	380
Total IP Reinjection					**2370**	**2290**	
Total SD-5 Reinjection/Infiltration							
28RIW0001	47	7	47	7	75	65	47
28RIW0002	49	9	49	9	75	65	47
28RIW0003	47	7	47	7	75	65	47
28RIW0004	45	5	45	5	75	65	47
28RIW0005	45	5	45	5	75	65	47
28RIW0006	45	3	45	3	75	65	47
28RIW0007	46	6	46	6	75	65	47
28RIW0008	44	4	44	4	75	65	47
Total SD-5 Reinjection					**600**	**521**	**375**

Notes:
Revisions are highlighted in blue.
Negative pumping rates mean extraction, positive rates mean injection/infiltration.
Current indicates CS-10 2012 Scenario 01 operating conditions.
Two screen setting values for 03EW2170 (top screen), 03EW2112 (bottom screen) and 03EW2110 (top screen) are listed for Alternative 10, Current Pumping scenarios.
-x indicates flow rate varies at this extraction well in Optimized Scenarios 1 through 7 (Refer to Table 2 for flow rates).
For Scenarios 5, 6 and 7 animations; some flow rates change in 2015 after 03EW2113 and/or 03EW2114 are operational.
03EW2114 is connected to a MTU with new infiltration trench.

Key:
ft msl = feet mean sea level
gpm = gallons per minute
IP = In-Plume
lbs = pounds
MTU = mobile treatment unit
ROD = Record of Decision
SD = Storm Drain
SR = Sandwich Road

Table 2
CS-10 Remedial System Flow Rates Under Current and Optimized Operating Scenarios
Final CS-10 2013 Technical Memorandum: Focused Feasibility Study for Remedial System Optimization

Location	Easting (ft)	Northing (ft)	Alternative 10/ Current Screen Setting		Optimized Screen Setting		Baseline Pumping Rates (gpm)		Phase I				Phase II		
			Top Screen Elevation (ft msl)	Bottom Screen Elevation (ft msl)	Top Screen Elevation (ft msl)	Bottom Screen Elevation (ft msl)	Alternative 10 (Pumping Scenario in ROD)	Current Pumping Scenario (2012 Scenario 01)	Optimized Scenario 1	Optimized Scenario 2	Optimized Scenario 3	Optimized Scenario 4	Optimized Scenario 5	Optimized Scenario 6	Optimized Scenario 7
Sandwich Road Extraction															
03EW2170	862736	234280	-100, -14	-164	-14	-164	-170	0	0	0	0	0	0	0	0
03EW2171	862892	234435	-101	-157	-101	-157	-75	-75	-75	-75	-75	-75	-75	-75	-75
03EW2172	862963	234667	-79	-163	-79	-163	-75	-75	-75	-75	-75	-75	-75	-75	-75
03EW2173	863134	234827	-79	-165	-125	-165	-100	-100	-110	-110	-110	-110	-110	-110	-110
03EW2174	863221	235014	-79	-163	-79	-163	-100	-100	-110	-110	-110	-110	-110	-110	-110
03EW2175	863334	235188	-103	-164	-103	-164	-60	-60	-60	-60	-60	-60	-60	-60	-60
03EW2176	863497	235309	-125	-167	-125	-167	0	-75	-40	-40	-40	-40	-40	-40	-40
03EW2177	863749	235450	-125	-159	-125	-159	0	-50	-60	-60	-60	-60	-60	-60	-60
03EW2112	862052	232199	-90	-150, -110	-90	-110	-290	-100	-100	-100	-100	-100	-100	-100	-100
Total SR Extraction							**-870**	**-635**	**-630**	**-630**	**-630**	**-630**	**-630**	**-630**	**-630**
Sandwich Road Reinjection															
03RI2180	862298	233616	-51	-151	-51	-151	0	0	0	0	0	0	0	0	0
03RI2181	862403	233839	-58	-158	-58	-158	0	0	0	0	0	0	0	0	0
03RI2182	862589	234120	-3	-73	-3	-73	0	0	0	0	0	0	0	0	0
03RI2183	864064	235658	11	-105	11	-105	120	40	120	120	120	120	120	120	120
03RI2184	864257	235832	-1	-160	-1	-160	162	156	162	162	162	162	162	162	162
03RI2185	864510	236022	-6	-156	-6	-156	163	108	163	163	163	163	163	163	163
Total SR Reinjection							**445**	**304**	**445**	**445**	**445**	**445**	**445**	**445**	**445**
Total In-Plume Extraction															
03EW2102	858952	242823	-70	-131	-90	-131	-460	-460	-460	-425	-650	-650	-550, -450	-650	-550, -450
03EW2103	859806	239179	-30	-70	-30	-70	-300	-300	-375	-375	-375	-375	-375, -300	-375	-375, -300
03EW2104	857773	241975	10	-100	-100	-136	-230	-230	-275	-425	-275	-425	-275	-275	-275
03EW2105	859752	241291	2	-40	2	-40	-450	-450	-450	-450	-450	-450	-450	-450	-450
03EW2106	860382	240984	18	-57	-30	-57	-80	0	0	0	0	0	0	0	0
03EW2107	856741	241230	6	-50	-30	-50	-50	-50	-150	-150	-60	-150	-150, -100	-150	-150, -100
03EW2109	861708	236634	-24	-114	-66	-114	-125	-125	-125	-125	-125	-125	-125	-125	-125
03EW2110	860243	243932	10, -40	-70	-40	-70	-250	-250	-100	-100	-100	-100	-100	-100	-100
03EW2111	861004	235979	-53	-98	-53	-98	-425	-425	-400	-400	-400	-400	-400	-400	-400
03EW2113	858610	241740	NA	NA	-110	-160	NA	NA	NA	NA	NA	NA	0, -375	NA	0, -375
03EW2114	862028	240659	NA	NA	-50	-70	NA	NA	NA	NA	NA	NA	NA	0, -125	0, -125
Total IP Extraction							**-2370**	**-2290**	**-2335**	**-2450**	**-2435**	**-2675**	**-2425, -2575**	**-2525, -2650**	**-2425, -2700**
Total In-Plume Reinjection/Infiltration															
Southern Infiltration Trench	857550	237525	56	48	56	48	1232	1232	782	828	822	918	1145, 1229	1201	1145, 1229
Southwest Infiltration Trench	855650	240275	58	53	58	53	758	678	1173	1242	1233	1377	900, 966	944	900, 966
03RI2112	861404	235344	-100	-190	-100	-190	380	380	380	380	380	380	380	380	380
MTU Infiltration Trench	862515	240650	NA	NA	60	55	NA	NA	NA	NA	NA	NA	NA	0, 125	0, 125
Total IP Reinjection							**2370**	**2290**	**2335**	**2450**	**2435**	**2675**	**2425, 2575**	**2525, 2650**	**2425, 2700**
Total Northern Lobe Extraction															
00EW0001	866114	231986	-26	-66	-26	-66	-175	-190	-190	-190	-190	-190	-190	-190	-190
Total NL Extraction							**-175**	**-190**	**-190**	**-190**	**-190**	**-190**	**-190**	**-190**	**-190**
Total SD-5 Reinjection/Infiltration															
28RIW0001	865406	235942	47	7	47	7	75	65	47	47	47	47	47	47	47
28RIW0002	865350	235969	49	9	49	9	75	65	47	47	47	47	47	47	47
28RIW0003	865312	235984	47	7	47	7	75	65	47	47	47	47	47	47	47
28RIW0004	865198	236048	45	5	45	5	75	65	47	47	47	47	47	47	47
28RIW0005	864754	236222	45	5	45	5	75	65	47	47	47	47	47	47	47
28RIW0006	864705	236230	45	3	45	3	75	65	47	47	47	47	47	47	47
28RIW0007	864661	236240	46	6	46	6	75	65	47	47	47	47	47	47	47
28RIW0008	864621	236232	44	4	44	4	75	65	47	47	47	47	47	47	47
Total SD-5 Reinjection							**600**	**521**	**375**	**375**	**375**	**375**	**375**	**375**	**375**
Summary															
Total IP Extraction							**-2370**	**-2290**	**-2335**	**-2450**	**-2435**	**-2675**	**-2425, -2575**	**-2525, -2650**	**-2425, -2700**
Total IP Reinjection							**2370**	**2290**	**2335**	**2450**	**2435**	**2675**	**2425, 2575**	**2525, 2650**	**2425, 2700**
Total SR/NL Extraction							**-1045**	**-825**	**-820**	**-820**	**-820**	**-820**	**-820**	**-820**	**-820**
Total SR/SD-5 Reinjection							**1045**	**825**	**820**	**820**	**820**	**820**	**820**	**820**	**820**

Notes:
Revisions are highlighted in blue.
Negative pumping rates mean extraction, positive rates mean injection/infiltration.
Current indicates CS-10 2012 Scenario 01 operating conditions.
Two screen setting values for 03EW2170 (top screen), 03EW2112 (bottom screen) and 03EW2110 (top screen) are listed for Alternative 10, Current Pumping scenarios.
For Scenarios 5,6 and 7 animations; some flow rates change in 2015 after 03EW2113 and/or 03EW2114 are installed. 03EW2114 is connected to a MTU with new infiltration trench.

Key:
ft = feet
gpm = gallons per minute
IP = In-Plume
msl = mean sea level
MTU = mobile treatment unit
NA = not applicable
NL = Northern lobe
ROD = Record of Decision
SD = Storm Drain
SR = Sandwich Road

Table 3
Hydraulic Capture Statistics
Final CS-10 2013 Technical Memorandum: Focused Feasibility Study for Remedial System Optimization

Scenarios	Initial Dissolved TCE Mass Outside Capture Zone (lbs)	Initial TCE Plume Volume Outside Capture Zone (Mgal)	Initial Dissolved TCE Mass Outside Capture Zone (%)	Initial Plume Volume Outside Capture Zone (%)
Baseline Scenarios				
Alternative 10/2007 Plume Shell	55.1	359	4.9	7.5
Current/2012 Plume Shell	472.3	1739	20.9	27.3
Optimized Scenarios				
Optimized Scenario 1	121.0	659	5.4	10.3
Optimized Scenario 2	66.8	490	3.0	7.7
Optimized Scenario 3	75.1	570	3.3	8.9
Optimized Scenario 4	44.4	370	2.0	5.8
Optimized Scenario 5	44.7	389	2.0	6.1
Optimized Scenario 6	49.5	406	2.2	6.4
Optimized Scenario 7	44.8	392	2.0	6.2

Notes:
Modeling of Alternative 10 was completed with the 2007 TCE plume shell and 2007 groundwater flow model.
Modeling of all other scenarios listed was completed with the 2012 TCE plume shell and 2012 groundwater flow model.
Current indicates CS-10 2012 Scenario 01 operating conditions.
Initial indicates time zero, i.e., plume mass and volume located outside composite capture zone at time zero.

Key:
lbs = pounds
Mgal = million gallons
TCE = trichloroethene

Table 4
CS-10 Plume Model - TCE Contaminant Transport Parameters
Final CS-10 2013 Technical Memorandum: Focused Feasibility Study for Remedial System Optimization

Aquifer Related Parameters				
Dispersivity (ft)			Porosity	Bulk Density (g/ml)
Longitudinal	Transverse	Vertical		
10	0.3	0.03	0.3	1.68
Contaminant Related Parameters				
Soil Water Partition Coefficient			Calculated Retardation Factor	Decay Half-Life (yrs)
Koc (ml/g)	Foc	Kd (ml/g)		
94	0.00038	0.04	1.20	60.00

Notes:
ft = feet
g = grams
Kd = Koc * Foc
Koc is organic carbon partition coefficient
Foc is soil organic carbon fraction
Kd is soil water partition coefficient
ml = milliliter
yrs = years

Table 5
Restoration Timeframes and Remedial System Mass Removal Estimates
Final CS-10 2013 Technical Memorandum: Focused Feasibility Study for Remedial System Optimization

	Alternative 10	Current	Scenario 4	Scenario 5	Scenario 6	Scenario 7
Estimated Year for Aquifer Restoration						
In-Plume	2094	>100 yrs *	2106	2060	>100 yrs *	2056
Sandwich Road	2038	2055	2055	2055	2038	2038
Southern Trench	2020	2020	2020	2020	2020	2020
Estimated Year for System Shutdown						
In-Plume	2055	2065	2055	2055	2055	2055
Sandwich Road	2030	2055	2055	2055	2035	2035
Total TCE Mass Removal Estimate through System Shutdown Year (lbs)						
	1191	2030	2337	2325	2312	2341

Notes:

Modeling of Alternative 10 was completed with the 2007 TCE plume shell and 2007 groundwater flow model.

Modeling of all other scenarios listed was completed with the 2012 TCE plume shell and 2012 groundwater flow model.

The 2007 TCE plume shell has 1,121 lbs and 4,447 million gallons of TCE at concentrations above the MCL.

The 2012 TCE plume shell has 2,270 lbs and 6,042 million gallons of TCE at concentrations above the MCL.

Values presented for Alternative 10 were taken from the *Final Record of Decision for Chemical Spill-10 Groundwater* (AFCEE 2009).

Current indicates CS-10 2012 Scenario 01 operating conditions.

* - Aquifer restoration (plume cleanup below MCLs) was not achieved at end of 100 year run in animation.

Key:

lbs = pounds

MCL = Maximum Contaminant Level

TCE = trichloroethene

yrs = years

Table 6
TCE Plume Mass and Volume Remaining After 2055
Final CS-10 2013 Technical Memorandum: Focused Feasibility Study for Remedial System Optimization

Scenarios	Dissolved TCE Plume Mass Remaining After 2055 (lbs)	TCE Plume Mass Remaining After 2055 (%)	Plume Volume Remaining After 2055 (Mgal)	Plume Volume Remaining After 2055 (%)	Maximum TCE Concentration After 2055 (µg/L)	Average TCE Concentration Remaining in Plume (µg/L)
Baseline Scenarios						
Alternative 10/2007 Plume Shell	5.4	0.5	51	1.1	28	12
Current/2012 Plume Shell	128	5.7	967	15.2	75	16
Optimized Scenarios						
Optimized Scenario 1	47.8	2.1	293	4.6	57	20
Optimized Scenario 2	24.3	1.1	277	4.4	37	10
Optimized Scenario 3	25.6	1.1	265	4.2	39	12
Optimized Scenario 4	16.7	0.7	209	3.3	28	10
Optimized Scenario 5	1.5	0.1	33	0.5	7	5
Optimized Scenario 6	28.4	1.3	277	4.4	46	12
Optimized Scenario 7	0.2	0.0	4	0.1	6	6

Notes:
Modeling of Alternative 10 was completed with the 2007 TCE plume shell and 2007 groundwater flow model.
Modeling of all other scenarios listed was completed with the 2012 TCE plume shell and 2012 groundwater flow model.
Current indicates CS-10 2012 Scenario 01 operating conditions.

Key:
lbs = pounds
Mgal = million gallons
TCE = trichloroethene
µg/L = micrograms per liter

Table 7
Proposed Infrastructure Requirements for Optimized Operating Scenarios
Final CS-10 2013 Technical Memorandum: Focused Feasibility Study for Remedial System Optimization

Scenario	Infrastructure Requirements
Optimized Scenario 1	6 pump/motor changes
Optimized Scenario 2	7 pump/motor changes and major electrical upgrade at 03EW2104
Optimized Scenario 3	5 pump/motor changes
Optimized Scenario 4	8 pump/motor changes and major electrical upgrade at 03EW2104
Optimized Scenario 5	1 new extraction well and pipeline; 7 pump/motor changes at existing extraction wells
Optimized Scenario 6	1 new extraction well, pipeline, trench, and MTU; 7 pump/motor changes at existing extraction wells
Optimized Scenario 7	2 new extraction wells, pipeline, trench, and MTU; 7 pump/motor changes at existing extraction wells

Note:
Proposed pump/motor requirements are included in Appendix B.

Key:
MTU = mobile treatment unit

Table 8
Cost Estimates for Optimized Scenarios
Final CS-10 2013 Technical Memorandum: Focused Feasibility Study for Remedial System Optimization

Scenario	Implementation Cost (million $)	Electrical Cost (million $)	Monitoring Cost (million $)	Future Lifecycle Cost (million $)
Current	0.00	20.9	31.8	52.7
Optimized Scenario 4	0.09	24.6	31.2	55.9
Optimized Scenario 5	1.01	24.8	24.7	50.6
Optimized Scenario 6	1.02	23.5	31.2	55.7
Optimized Scenario 7	2.00	23.6	24.7	50.4

Notes:
The future remedial action cost estimate for Alternative 10 presented in the Interim Remedial Action Report is $50.2 million.
Current indicates CS-10 2012 Scenario 01 operating conditions.

Table 9
Estimates of Carbon Dioxide Emissions for Optimized Scenarios
Final CS-10 2013 Technical Memorandum: Focused Feasibility Study for Remedial System Optimization

Scenario	Electrical Consumption [megawatt hours]	Carbon Dioxide Emissions [tons]*
Alternative 10	101.4	66.4
Current	130.6	85.5
Optimized Scenario 4	153.7	100.6
Optimized Scenario 5	155.1	101.6
Optimized Scenario 6	146.6	96.0
Optimized Scenario 7	147.7	96.7

Notes:
Current indicates CS-10 2012 Scenario 01 operating conditions.

* Assumes carbon dioxide emissions of 1.31 pounds per kilowatt hour.

Air emissions are based on electricity produced by the average mix of generation sources in Massachusetts.

CO_2 emission factor obtained from the following sources:

http://www.csgnetwork.com/elecpowerpolcalc.html

http://www.metrixcentral.com/EmissionsCalculator/Emissions%20Factors%202004.pdf

APPENDIX A

CS-10 Groundwater Modeling Transport Animations

(On Enclosed CD)

APPENDIX B

Proposed Pump and Motor Requirements for Optimized Scenarios

Appendix B
Proposed Pump and Motor Requirements for Optimized Scenarios
Final CS-10 2013 Technical Memorandum: Focused Feasibility Study for Remedial System Optimization

Location	Optimized Scenario 4		Optimized Scenario 5		Optimized Scenario 6		Optimized Scenario 7	
	Flow Rate (gpm)	Preliminary Pump/Motor Requirement	Flow Rate (gpm)	Preliminary Pump/Motor Requirement	Flow Rate (gpm)	Preliminary Pump/Motor Requirement	Flow Rate (gpm)	Preliminary Pump/Motor Requirement
Existing Extraction Wells								
03EW2173	-110	5CLC-7, 3.56", 20 HP	-110	5CLC-7, 3.56", 20 HP	-110	5CLC-7, 3.56", 20 HP	-110	5CLC-7, 3.56", 20 HP
03EW2176	-40	6RAHC-4, 3.69", 5 HP	-40	6RAHC-4, 3.69", 5 HP	-40	6RAHC-4, 3.69", 5 HP	-40	6RAHC-4, 3.69", 5 HP
03EW2177	-60	5RWALC-4, 3.5" 5 HP	-60	5RWALC-4, 3.5" 5 HP	-60	5RWALC-4, 3.5" 5 HP	-60	5RWALC-4, 3.5" 5 HP
03EW2102	-650	7THC-3, 4.81", 50 HP	-550, -450	7TLC-4, 4.56", 40 HP	-650	7THC-3, 4.81", 50 HP	-550, -450	7TLC-4, 4.56", 40 HP
03EW2103	-375	7CLC-3, 4.81", 30 HP	-375, -300	7CLC-3, 4.81", 30 HP	-375	7CLC-3, 4.81", 30 HP	-375, -300	7CLC-3, 4.81", 30 HP
03EW2104	-425	7CHC-3, 5.25", 50 HP	-275		-275		-275	
03EW2107	-150	6CLC-5, 4.06", 15 HP	-150, -100	6CLC-5, 3.94", 15 HP	150	6CLC-5, 3.94", 15 HP	-150, -100	6CLC-5, 3.94", 15 HP
03EW2110	-100	5CLC-4, 3.75", 7.5 HP	-100	5CLC-4, 3.75", 7.5 HP	-100	5CLC-4, 3.75", 7.5 HP	-100	5CLC-4, 3.75", 7.5 HP
New Extraction Wells								
03EW2113	NA		0, -375	7TLC-4, 4.75", 40 HP	NA		0, -375	7TLC-4, 4.75", 40 HP
03EW2114	NA		NA		0,-125	5CLC-5, 3.72", 10 HP	0, -125	5CLC-5, 3.72", 10 HP

Key:

gpm = gallons per minute
HP = horsepower
NA = not applicable

APPENDIX C

Future Lifecycle Cost Estimates

Table C-1a
Current Operating Conditions (CS-10 2012 Scenario 01) - Electrical Cost Summary
Final CS-10 2013 Technical Memorandum: Focused Feasibility Study for Remedial System Optimization

Location	2012		2020		2035		2040		2045		2050		2055	
	Power (hp)	Annual Cost	Power (hp)	Annual Cost	Power (hp)	Annual Cost	Power (hp)	Annual Cost	Power (hp)	Annual Cost	Power (hp)	Annual Cost	Power (hp)	Annual Cost
03EW2170	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0
03EW2171	11.9	$23,683	11.9	$23,683	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0
03EW2172	10.8	$22,362	10.8	$22,362	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0
03EW2173	8.5	$19,787	8.5	$19,787	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0
03EW2174	12.5	$24,384	12.5	$24,384	12.5	$24,384	12.5	$24,384	12.5	$24,384	12.5	$24,384	0.0	$0
03EW2175	6.7	$17,667	6.7	$17,667	6.7	$17,667	6.7	$17,667	6.7	$17,667	6.7	$17,667	0.0	$0
03EW2176	9.0	$20,307	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0
03EW2177	10.8	$22,421	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0
03EW2112	5.9	$16,709	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0
03EW2111	56.4	$75,686	56.4	$75,686	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0
03EW2110	13.1	$25,050	13.1	$25,050	13.1	$25,050	0.0	$0	0.0	$0	0.0	$0	0.0	$0
03EW2109	19.1	$32,167	19.1	$32,167	19.1	$32,167	0.0	$0	0.0	$0	0.0	$0	0.0	$0
03EW2107	4.0	$14,472	4.0	$14,472	4.0	$14,472	4.0	$14,472	0.0	$0	0.0	$0	0.0	$0
03EW2106	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0
03EW2105	36.3	$52,174	36.3	$52,174	36.3	$52,174	0.0	$0	0.0	$0	0.0	$0	0.0	$0
03EW2104	16.5	$29,035	16.5	$29,035	16.5	$29,035	16.5	$29,035	16.5	$29,035	16.5	$29,035	0.0	$0
03EW2102	22.1	$35,661	22.1	$35,661	22.1	$35,661	22.1	$35,661	22.1	$35,661	0.0	$0	0.0	$0
03EW2103	15.9	$28,357	15.9	$28,357	15.9	$28,357	15.9	$28,357	15.9	$28,357	15.9	$28,357	15.9	$28,357
All EWs		$459,923		$400,487		$258,968		$149,577		$135,105		$99,444		$28,357
SR Plant Costs[1]		$98,842		$65,454		$24,956		$24,956		$24,956		$24,956		$0
IP Plant Costs[1]		$173,550		$173,550		$120,169		$55,359		$51,573		$30,620		$15,036
Total Annual Electrical Cost		$732,315		$639,490		$404,093		$229,892		$211,635		$155,020		$43,393

Note:
1. Assumes costs and flow rates from October 2011 - September 2012 as baseline, pro-rated to design flow.

Key:
EW = extraction well
hp = horsepower
IP = In-Plume
SR = Sandwich Road

Table C-1b
Current Operating Conditions (CS-10 2012 Scenario 01) - Future Lifecycle Cost Summary
Final CS-10 2013 Technical Memorandum: Focused Feasibility Study for Remedial System Optimization

Year	Implementation Costs	Electrical Cost[1]	Monitoring Cost[2]	Total Cost
2012		$732,315	$1,088,807	$1,821,122
2013		$732,315	$575,150	$1,307,465
2014		$732,315	$1,088,807	$1,821,122
2015		$732,315	$575,150	$1,307,465
2016		$732,315	$994,757	$1,727,072
2017		$732,315	$531,743	$1,264,058
2018		$732,315	$994,757	$1,727,072
2019		$732,315	$531,743	$1,264,058
2020		$639,490	$907,942	$1,547,432
2021		$639,490	$491,953	$1,131,443
2022		$639,490	$907,942	$1,547,432
2023		$639,490	$491,953	$1,131,443
2024		$639,490	$907,942	$1,547,432
2025		$639,490	$491,953	$1,131,443
2026		$639,490	$831,979	$1,471,469
2027		$639,490	$455,780	$1,095,270
2028		$639,490	$831,979	$1,471,469
2029		$639,490	$455,780	$1,095,270
2030		$639,490	$763,250	$1,402,740
2031		$639,490	$423,224	$1,062,714
2032		$639,490	$763,250	$1,402,740
2033		$639,490	$423,224	$1,062,714
2034		$639,490	$763,250	$1,402,740
2035		$404,093	$423,224	$827,317
2036		$404,093	$701,756	$1,105,849
2037		$404,093	$394,286	$798,379
2038		$404,093	$701,756	$1,105,849
2039		$404,093	$307,470	$711,563
2040		$229,892	$578,768	$808,660
2041		$229,892	$307,470	$537,362
2042		$229,892	$542,595	$772,487
2043		$229,892	$289,384	$519,276
2044		$229,892	$506,422	$736,314
2045		$211,635	$289,384	$501,019
2046		$211,635	$470,249	$681,884
2047		$211,635	$253,211	$464,846
2048		$211,635	$434,076	$645,711
2049		$211,635	$253,211	$464,846
2050		$155,020	$397,903	$552,923
2051		$155,020	$217,038	$372,058
2052		$155,020	$361,730	$516,750
2053		$155,020	$198,951	$353,971
2054		$155,020	$325,557	$480,577
2055		$43,393	$198,951	$242,344
2056		$43,393	$293,001	$336,394
2057		$43,393	$166,396	$209,789
2058		$43,393	$293,001	$336,394
2059		$43,393	$148,309	$191,702
2060		$43,393	$256,828	$300,221
2061		$43,393	$148,309	$191,702
2062		$43,393	$256,828	$300,221
2063		$43,393	$148,309	$191,702
2064		$43,393	$256,828	$300,221
2065			$130,223	$130,223
2066			$220,655	$220,655
2067			$130,223	$130,223
2068			$220,655	$220,655
2069			$130,223	$130,223

Table C-1b
Current Operating Conditions (CS-10 2012 Scenario 01) - Future Lifecycle Cost Summary
Final CS-10 2013 Technical Memorandum: Focused Feasibility Study for Remedial System Optimization

Year	Implementation Costs	Electrical Cost[1]	Monitoring Cost[2]	Total Cost
2070			$220,655	$220,655
2071			$130,223	$130,223
2072			$220,655	$220,655
2073			$122,988	$122,988
2074			$184,482	$184,482
2075			$97,667	$97,667
2076			$159,161	$159,161
2077			$97,667	$97,667
2078			$159,161	$159,161
2079			$86,815	$86,815
2080			$122,988	$122,988
2081			$86,815	$86,815
2082			$122,988	$122,988
2083			$86,815	$86,815
2084			$122,988	$122,988
2085			$79,581	$79,581
2086			$115,754	$115,754
2087			$79,581	$79,581
2088			$115,754	$115,754
2089			$79,581	$79,581
2090			$115,754	$115,754
2091			$68,729	$68,729
2092			$104,902	$104,902
2093			$68,729	$68,729
2094			$104,902	$104,902
2095			$68,729	$68,729
2096			$104,902	$104,902
2097			$68,729	$68,729
2098			$104,902	$104,902
2099			$68,729	$68,729
2100			$104,902	$104,902
2101			$68,729	$68,729
2102			$104,902	$104,902
2103			$68,729	$68,729
2104			$104,902	$104,902
2105			$68,729	$68,729
2106			$104,902	$104,902
2107			$68,729	$68,729
2108			$104,902	$104,902
2109			$68,729	$68,729
2110			$104,902	$104,902
2111			$68,729	$68,729
2112			$104,902	$104,902
Total	$0	$20,888,007	$31,763,509	
			Total Lifecycle Cost	$52,651,516

Notes:

1. Assumes costs and flow rates from October 2011 - September 2012 as baseline, pro-rated to design flow.
2. Monitoring costs from table "CS-10 Present Value SPEIM/O&M Costs", *Final CS-10, Ashumet Valley Plumes Updated Interim Remedial Action Report*.

Table C-2a
Optimized Scenario 4 - Electrical Cost Summary
Final CS-10 2013 Technical Memorandum: Focused Feasibility Study for Remedial System Optimization

Location	2012		2020		2035		2040		2045		2050	
	Power (hp)	Annual Cost	Power (hp)	Annual Cost	Power (hp)	Annual Cost	Power (hp)	Annual Cost	Power (hp)	Annual Cost	Power (hp)	Annual Cost
03EW2170	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0
03EW2171	11.9	$23,683	11.9	$23,683	0.0	$0	0.0	$0	0.0	$0	0.0	$0
03EW2172	10.8	$22,362	10.8	$22,362	0.0	$0	0.0	$0	0.0	$0	0.0	$0
03EW2173	11.1	$22,772	11.1	$22,772	0.0	$0	0.0	$0	0.0	$0	0.0	$0
03EW2174	13.2	$25,261	13.2	$25,261	13.2	$25,261	13.2	$25,261	13.2	$25,261	13.2	$25,261
03EW2175	6.7	$17,630	6.7	$17,630	6.7	$17,630	6.7	$17,630	6.7	$17,630	6.7	$17,630
03EW2176	3.3	$13,656	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0
03EW2177	3.4	$13,773	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0
03EW2112	5.9	$16,695	0.0	$0	0.0	$0	0	$0	0.0	$0	0.0	$0
03EW2111	51.1	$69,481	51.1	$69,481	51.1	$69,481	0.0	$0	0	$0	0.0	$0
03EW2110	4.7	$15,340	4.7	$15,340	4.7	$15,340	4.7	$15,340	0.0	$0	0.0	$0
03EW2109	19.1	$32,167	19.1	$32,167	19.1	$32,167	0.0	$0	0.0	$0	0.0	$0
03EW2107	14.0	$26,125	14.0	$26,125	14.0	$26,125	0.0	$0	0.0	$0	0.0	$0
03EW2106	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0
03EW2105	36.3	$52,174	36.3	$52,174	36.3	$52,174	36.3	$52,174	0.0	$0	0.0	$0
03EW2104	45.4	$62,808	45.4	$62,808	45.4	$62,808	45.4	$62,808	45.4	$62,808	45.4	$62,808
03EW2102	44.7	$62,013	44.7	$62,013	44.7	$62,013	44.7	$62,013	0.0	$0	0.0	$0
03EW2103	26.4	$40,628	26.4	$40,628	26.4	$40,628	26.4	$40,628	26.4	$40,628	26.4	$40,628
All EWs		$516,568		$472,443		$403,626		$275,853		$146,326		$146,326
SR Plant Costs[1]		$98,063		$79,416		$29,496		$29,496		$29,496		$29,496
IP Plant Costs[1]		$173,553		$173,553		$173,553		$113,082		$51,534		$51,534
Total Annual Electrical Cost		$788,184		$725,412		$606,675		$418,432		$227,356		$227,356

Note:

1. Assumes costs and flow rates from October 2011 - September 2012 as baseline, pro-rated to design flow.

Key:
EW = extraction well
hp = horsepower
IP = In-Plume
SR = Sandwich Road

Table C-2b
Optimized Scenario 4 - Future Lifecycle Cost Summary
Final CS-10 2013 Technical Memorandum: Focused Feasibility Study for Remedial System Optimization

Year	Implementation Costs	Electrical Cost[1]	Monitoring Cost[2]	Total Cost
2012		$788,184	$1,088,807	$1,876,991
2013	$90,000	$788,184	$575,150	$1,453,334
2014		$788,184	$1,088,807	$1,876,991
2015		$788,184	$575,150	$1,363,334
2016		$788,184	$994,757	$1,782,941
2017		$788,184	$531,743	$1,319,927
2018		$788,184	$994,757	$1,782,941
2019		$788,184	$531,743	$1,319,927
2020		$725,412	$907,942	$1,633,354
2021		$725,412	$491,953	$1,217,365
2022		$725,412	$907,942	$1,633,354
2023		$725,412	$491,953	$1,217,365
2024		$725,412	$907,942	$1,633,354
2025		$725,412	$491,953	$1,217,365
2026		$725,412	$831,979	$1,557,391
2027		$725,412	$455,780	$1,181,192
2028		$725,412	$831,979	$1,557,391
2029		$725,412	$455,780	$1,181,192
2030		$725,412	$763,250	$1,488,662
2031		$725,412	$423,224	$1,148,636
2032		$725,412	$763,250	$1,488,662
2033		$725,412	$423,224	$1,148,636
2034		$725,412	$763,250	$1,488,662
2035		$606,675	$423,224	$1,029,899
2036		$606,675	$701,756	$1,308,431
2037		$606,675	$394,286	$1,000,961
2038		$606,675	$701,756	$1,308,431
2039		$606,675	$307,470	$914,145
2040		$418,432	$578,768	$997,200
2041		$418,432	$307,470	$725,902
2042		$418,432	$542,595	$961,027
2043		$418,432	$289,384	$707,816
2044		$418,432	$506,422	$924,854
2045		$227,356	$289,384	$516,740
2046		$227,356	$470,249	$697,605
2047		$227,356	$253,211	$480,567
2048		$227,356	$434,076	$661,432
2049		$227,356	$253,211	$480,567
2050		$227,356	$397,903	$625,259
2051		$227,356	$217,038	$444,394
2052		$227,356	$361,730	$589,086
2053		$227,356	$198,951	$426,307
2054		$227,356	$325,557	$552,913
2055			$198,951	$198,951
2056			$293,001	$293,001
2057			$166,396	$166,396
2058			$293,001	$293,001
2059			$148,309	$148,309
2060			$256,828	$256,828
2061			$148,309	$148,309
2062			$256,828	$256,828
2063			$148,309	$148,309
2064			$256,828	$256,828
2065			$130,223	$130,223
2066			$220,655	$220,655
2067			$130,223	$130,223
2068			$220,655	$220,655
2069			$130,223	$130,223

Table C-2b
Optimized Scenario 4 - Future Lifecycle Cost Summary
Final CS-10 2013 Technical Memorandum: Focused Feasibility Study for Remedial System Optimization

Year	Implementation Costs	Electrical Cost[1]	Monitoring Cost[2]	Total Cost
2070			$220,655	$220,655
2071			$130,223	$130,223
2072			$220,655	$220,655
2073			$122,988	$122,988
2074			$184,482	$184,482
2075			$97,667	$97,667
2076			$159,161	$159,161
2077			$97,667	$97,667
2078			$159,161	$159,161
2079			$86,815	$86,815
2080			$122,988	$122,988
2081			$86,815	$86,815
2082			$122,988	$122,988
2083			$86,815	$86,815
2084			$122,988	$122,988
2085			$79,581	$79,581
2086			$115,754	$115,754
2087			$79,581	$79,581
2088			$115,754	$115,754
2089			$79,581	$79,581
2090			$115,754	$115,754
2091			$68,729	$68,729
2092			$104,902	$104,902
2093			$68,729	$68,729
2094			$104,902	$104,902
2095			$68,729	$68,729
2096			$104,902	$104,902
2097			$68,729	$68,729
2098			$104,902	$104,902
2099			$68,729	$68,729
2100			$104,902	$104,902
2101			$68,729	$68,729
2102			$104,902	$104,902
2103			$68,729	$68,729
2104			$104,902	$104,902
2105			$68,729	$68,729
2106			$104,902	$104,902
Total	$90,000	$24,585,733	$31,242,616	
			Total Lifecycle Cost	$55,918,349

Notes:

1. Assumes costs and flow rates from October 2011 - September 2012 as baseline, pro-rated to design flow.
2. Monitoring costs from table "CS-10 Present Value SPEIM/O&M Costs", *Final CS-10, Ashumet Valley Plumes Updated Interim Remedial Action Report*.

Table C-3a
Optimized Scenario 5 - Electrical Cost Summary
Final CS-10 2013 Technical Memorandum: Focused Feasibility Study for Remedial System Optimization

Location	2012		2014		2020		2035		2040		2045	
	Power (hp)	Annual Cost	Power (hp)	Annual Cost	Power (hp)	Annual Cost	Power (hp)	Annual Cost	Power (hp)	Annual Cost	Power (hp)	Annual Cost
03EW2170	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0
03EW2171	11.9	$23,683	11.9	$23,683	11.9	$23,683	0.0	$0	0.0	$0	0.0	$0
03EW2172	10.8	$22,362	10.8	$22,362	10.8	$22,362	0.0	$0	0.0	$0	0.0	$0
03EW2173	11.1	$22,772	11.1	$22,772	11.1	$22,818	0.0	$0	0.0	$0	0.0	$0
03EW2174	13.2	$25,261	13.2	$25,261	13.2	$25,261	13.2	$25,261	13.2	$25,261	13.2	$25,261
03EW2175	6.7	$17,630	6.7	$17,630	6.7	$17,630	6.7	$17,630	6.7	$17,630	6.7	$17,630
03EW2176	3.3	$13,656	3.3	$13,656	0.0	$0	0.0	$0	0.0	$0	0.0	$0
03EW2177	3.4	$13,773	3.4	$13,773	0.0	$0	0.0	$0	0.0	$0	0.0	$0
03EW2112	5.9	$16,695	5.9	$16,695	0.0	$0	0	$0	0.0	$0	0.0	$0
03EW2111	51.1	$69,481	49.7	$67,880	49.7	$67,880	49.7	$67,880	0.0	$0	0.0	$0
03EW2110	4.7	$15,340	4.7	$15,340	4.7	$15,340	4.7	$15,340	4.7	$15,340	0.0	$0
03EW2109	19.1	$32,167	19.1	$32,167	19.1	$32,167	19.1	$32,167	0.0	$0	0.0	$0
03EW2107	13.0	$24,992	11.7	$23,473	11.7	$23,473	11.7	$23,473	0.0	$0	0.0	$0
03EW2106	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0
03EW2105	36.3	$52,174	36.3	$52,174	36.3	$52,174	36.3	$52,174	0.0	$0	0.0	$0
03EW2104	19.1	$32,085	19.1	$32,085	19.1	$32,085	19.1	$32,085	19.1	$32,085	0.0	$0
03EW2102	35.1	$50,818	36.6	$52,571	36.6	$52,571	36.6	$52,571	36.6	$52,571	0.0	$0
03EW2103	26.4	$40,628	24.6	$38,548	24.6	$38,548	24.6	$38,548	24.6	$38,548	0.0	$0
03EW2113	0.0	$0	35.4	$51,169	35.4	$51,169	35.4	$51,169	35.4	$51,169	35.4	$51,169
03EW2114	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0
All EWs		$473,516		$521,238		$477,160		$408,296		$232,603		$94,059
SR Plant Costs[1]		$98,063		$98,063		$79,475		$29,496		$29,496		$29,496
IP Plant Costs[1]		$186,752		$216,348		$216,348		$216,348		$109,821		$32,287
Total Annual Electrical Cost		$758,332		$835,649		$772,983		$654,140		$371,920		$155,841

Note:
1. Assumes costs and flow rates from October 2011 - September 2012 as baseline, pro-rated to design flow.

Key:
EW = extraction well
hp = horsepower
IP = In-Plume
SR = Sandwich Road

Table C-3b
Optimized Scenario 5 - Future Lifecycle Cost Summary
Final CS-10 2013 Technical Memorandum: Focused Feasibility Study for Remedial System Optimization

Year	Implementation Costs[3]	Electrical Cost[1]	Monitoring Cost[2]	Total Cost
2012		$758,332	$1,088,807	$1,847,139
2013	$854,000	$758,332	$575,150	$2,340,482
2014		$835,649	$1,088,807	$1,924,456
2015		$835,649	$575,150	$1,410,799
2016		$835,649	$994,757	$1,830,406
2017		$835,649	$531,743	$1,367,392
2018		$835,649	$994,757	$1,830,406
2019		$835,649	$531,743	$1,367,392
2020		$772,983	$907,942	$1,680,925
2021		$772,983	$491,953	$1,264,936
2022		$772,983	$907,942	$1,680,925
2023		$772,983	$491,953	$1,264,936
2024		$772,983	$907,942	$1,680,925
2025		$772,983	$491,953	$1,264,936
2026		$772,983	$831,979	$1,604,962
2027		$772,983	$455,780	$1,228,763
2028		$772,983	$831,979	$1,604,962
2029		$772,983	$455,780	$1,228,763
2030		$772,983	$763,250	$1,536,233
2031		$772,983	$423,224	$1,196,207
2032		$772,983	$763,250	$1,536,233
2033		$772,983	$423,224	$1,196,207
2034		$772,983	$763,250	$1,536,233
2035		$654,140	$423,224	$1,077,364
2036		$654,140	$701,756	$1,355,896
2037		$654,140	$394,286	$1,048,426
2038		$654,140	$701,756	$1,355,896
2039		$654,140	$307,470	$961,610
2040		$371,920	$578,768	$950,688
2041		$371,920	$307,470	$679,390
2042		$371,920	$542,595	$914,515
2043		$371,920	$289,384	$661,304
2044		$371,920	$506,422	$878,342
2045		$155,841	$289,384	$445,225
2046		$155,841	$470,249	$626,090
2047		$155,841	$253,211	$409,052
2048		$155,841	$434,076	$589,917
2049		$155,841	$253,211	$409,052
2050		$155,841	$397,903	$553,744
2051		$155,841	$217,038	$372,879
2052		$155,841	$361,730	$517,571
2053		$155,841	$198,951	$354,792
2054		$155,841	$325,557	$481,398
2055			$198,951	$198,951
2056			$293,001	$293,001
Total	$854,000	$24,814,017	$24,738,708	
			Total Lifecycle Cost	$50,559,725

Notes:

1. Assumes costs and flow rates from October 2011 - September 2012 as baseline, pro-rated to design flow.
2. Monitoring costs from table "CS-10 Present Value SPEIM/O&M Costs", *Final CS-10, Ashumet Valley Plumes Updated Interim Remedial Action Report*.
3. Costs for new EW construction & installation from *Final CS-10, Ashumet Valley Plumes Updated Interim Remedial Action Report,* page 82.

Table C-4a
Optimized Scenario 6 - Electrical Cost Summary
Final CS-10 2013 Technical Memorandum: Focused Feasibility Study for Remedial System Optimization

Location	2012		2014		2020		2025		2035		2040		2045		2050	
	Power (hp)	Annual Cost	Power (hp)	Annual Cost	Power (hp)	Annual Cost	Power (hp)	Annual Cost	Power (hp)	Annual Cost	Power (hp)	Annual Cost	Power (hp)	Annual Cost	Power (hp)	Annual Cost
03EW2170	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0
03EW2171	11.9	$23,683	11.9	$23,683	11.9	$23,683	11.9	$23,683	0.0	$0	0.0	$0	0.0	$0	0.0	$0
03EW2172	10.8	$22,362	10.8	$22,362	10.8	$22,362	10.8	$22,362	0.0	$0	0.0	$0	0.0	$0	0.0	$0
03EW2173	11.1	$22,772	11.1	$22,772	11.1	$22,818	11.1	$22,818	0.0	$0	0.0	$0	0.0	$0	0.0	$0
03EW2174	13.2	$25,261	13.2	$25,261	13.2	$25,261	13.2	$25,261	0.0	$0	0.0	$0	0.0	$0	0.0	$0
03EW2175	6.7	$17,630	6.7	$17,630	6.7	$17,630	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0
03EW2176	3.3	$13,656	3.3	$13,656	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0
03EW2177	3.4	$13,773	3.4	$13,773	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0
03EW2112	5.9	$16,695	5.9	$16,695	0.0	$0	0.0	$0	0	$0	0.0	$0	0.0	$0	0.0	$0
03EW2111	51.0	$69,399	51.0	$69,399	51.0	$69,399	51.0	$69,399	51.0	$69,399	0.0	$0	0.0	$0	0.0	$0
03EW2110	4.7	$15,340	4.7	$15,340	4.7	$15,340	4.7	$15,340	4.7	$15,340	4.7	$15,340	0.0	$0	0.0	$0
03EW2109	19.1	$32,167	19.1	$32,167	19.1	$32,167	19.1	$32,167	19.1	$32,167	0.0	$0	0.0	$0	0.0	$0
03EW2107	13.0	$24,992	13.0	$24,992	13.0	$24,992	13.0	$24,992	13.0	$24,992	0.0	$0	0.0	$0	0.0	$0
03EW2106	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0
03EW2105	36.3	$52,174	36.3	$52,174	36.3	$52,174	36.3	$52,174	36.3	$52,174	36.3	$52,174	0.0	$0	0.0	$0
03EW2104	19.1	$32,085	19.1	$32,085	19.1	$32,085	19.1	$32,085	19.1	$32,085	19.1	$32,085	19.1	$32,085	19.1	$32,085
03EW2102	44.7	$62,037	44.7	$62,037	44.7	$62,037	44.7	$62,037	44.7	$62,037	44.7	$62,037	44.7	$62,037	0.0	$0
03EW2103	26.4	$40,628	26.4	$40,628	26.4	$40,628	26.4	$40,628	26.4	$40,628	26.4	$40,628	26.4	$40,628	26.4	$40,628
03EW2113	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0
03EW2114	0.0	$0	9.4	$20,785	9.4	$20,785	9.4	$20,785	9.4	$20,785	0.0	$0	0.0	$0	0.0	$0
All EWs		$484,653		$505,438		$461,360		$443,731		$349,606		$202,264		$134,750		$72,713
SR Plant Costs[1]		$98,063		$98,063		$79,475		$69,559		$0		$0		$0		$0
IP Plant Costs[1]		$173,525		$181,137		$181,137		$181,137		$181,137		$106,201		$73,000		$36,804
Total Annual Electrical Cost		$756,241		$784,638		$721,972		$694,426		$530,743		$308,465		$207,750		$109,517

Note:
1. Assumes costs and flow rates from October 2011 - September 2012 as baseline, pro-rated to design flow.

Key:
EW = extraction well
hp = horsepower
IP = In-Plume
SR = Sandwich Road

Table C-4b
Optimized Scenario 6 - Future Lifecycle Cost Summary
Final CS-10 2013 Technical Memorandum: Focused Feasibility Study for Remedial System Optimization

Year	Implementation Costs[3]	Electrical Cost[1]	Monitoring Cost[2]	Total Cost
2012		$756,241	$1,088,807	$1,845,048
2013	$1,173,000	$756,241	$575,150	$2,354,391
2014	$50,000	$784,638	$1,088,807	$1,873,445
2015		$784,638	$575,150	$1,359,788
2016		$784,638	$994,757	$1,779,395
2017		$784,638	$531,743	$1,316,381
2018		$784,638	$994,757	$1,779,395
2019		$784,638	$531,743	$1,316,381
2020		$721,972	$907,942	$1,629,914
2021		$721,972	$491,953	$1,213,925
2022		$721,972	$907,942	$1,629,914
2023		$721,972	$491,953	$1,213,925
2024		$721,972	$907,942	$1,629,914
2025		$694,426	$491,953	$1,186,379
2026		$721,972	$831,979	$1,553,951
2027		$721,972	$455,780	$1,177,752
2028		$721,972	$831,979	$1,553,951
2029		$721,972	$455,780	$1,177,752
2030		$721,972	$763,250	$1,485,222
2031		$721,972	$423,224	$1,145,196
2032		$721,972	$763,250	$1,485,222
2033		$721,972	$423,224	$1,145,196
2034		$721,972	$763,250	$1,485,222
2035		$530,743	$423,224	$953,967
2036		$694,426	$701,756	$1,396,182
2037		$694,426	$394,286	$1,088,712
2038		$694,426	$701,756	$1,396,182
2039		$694,426	$307,470	$1,001,896
2040		$308,465	$578,768	$887,233
2041		$308,465	$307,470	$615,935
2042		$308,465	$542,595	$851,060
2043		$308,465	$289,384	$597,849
2044		$308,465	$506,422	$814,887
2045		$207,750	$289,384	$497,134
2046		$207,750	$470,249	$677,999
2047		$207,750	$253,211	$460,961
2048		$207,750	$434,076	$641,826
2049		$207,750	$253,211	$460,961
2050		$109,517	$397,903	$507,420
2051		$109,517	$217,038	$326,555
2052		$109,517	$361,730	$471,247
2053		$109,517	$198,951	$308,468
2054		$109,517	$325,557	$435,074
2055			$198,951	$198,951
2056			$293,001	$293,001
2057			$166,396	$166,396
2058			$293,001	$293,001
2059			$148,309	$148,309
2060			$256,828	$256,828
2061			$148,309	$148,309
2062			$256,828	$256,828
2063			$148,309	$148,309
2064			$256,828	$256,828
2065			$130,223	$130,223
2066			$220,655	$220,655
2067			$130,223	$130,223
2068			$220,655	$220,655
2069			$130,223	$130,223

Table C-4b
Optimized Scenario 6 - Future Lifecycle Cost Summary
Final CS-10 2013 Technical Memorandum: Focused Feasibility Study for Remedial System Optimization

Year	Implementation Costs[3]	Electrical Cost[1]	Monitoring Cost[2]	Total Cost
2070			$220,655	$220,655
2071			$130,223	$130,223
2072			$220,655	$220,655
2073			$122,988	$122,988
2074			$184,482	$184,482
2075			$97,667	$97,667
2076			$159,161	$159,161
2077			$97,667	$97,667
2078			$159,161	$159,161
2079			$86,815	$86,815
2080			$122,988	$122,988
2081			$86,815	$86,815
2082			$122,988	$122,988
2083			$86,815	$86,815
2084			$122,988	$122,988
2085			$79,581	$79,581
2086			$115,754	$115,754
2087			$79,581	$79,581
2088			$115,754	$115,754
2089			$79,581	$79,581
2090			$115,754	$115,754
2091			$68,729	$68,729
2092			$104,902	$104,902
2093			$68,729	$68,729
2094			$104,902	$104,902
2095			$68,729	$68,729
2096			$104,902	$104,902
2097			$68,729	$68,729
2098			$104,902	$104,902
2099			$68,729	$68,729
2100			$104,902	$104,902
2101			$68,729	$68,729
2102			$104,902	$104,902
2103			$68,729	$68,729
2104			$104,902	$104,902
2105			$68,729	$68,729
2106			$104,902	$104,902
Total	$1,223,000	$23,459,453	$31,242,616	
			Total Lifecycle Cost	$55,725,069

Notes:

1. Assumes costs and flow rates from October 2011 - September 2012 as baseline, pro-rated to design flow.
2. Monitoring costs from table "CS-10 Present Value SPEIM/O&M Costs", *Final CS-10, Ashumet Valley Plumes Updated Interim Remedial Action Report*.
3. Costs for new MTU construction & installation from *Final CS-10, Ashumet Valley Plumes Updated Interim Remedial Action Report,* page 87.

Table C-5a
Optimized Scenario 7 - Electrical Cost Summary
Final CS-10 2013 Technical Memorandum: Focused Feasibility Study for Remedial System Optimization

Location	2012		2014		2020		2025		2035		2040		2045	
	Power (hp)	Annual Cost	Power (hp)	Annual Cost	Power (hp)	Annual Cost	Power (hp)	Annual Cost	Power (hp)	Annual Cost	Power (hp)	Annual Cost	Power (hp)	Annual Cost
03EW2170	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0
03EW2171	11.9	$23,683	11.9	$23,683	11.9	$23,683	11.9	$23,683	0.0	$0	0.0	$0	0.0	$0
03EW2172	10.8	$22,362	10.8	$22,362	10.8	$22,362	10.8	$22,362	0.0	$0	0.0	$0	0.0	$0
03EW2173	11.1	$22,772	11.1	$22,772	11.1	$22,818	11.1	$22,818	0.0	$0	0.0	$0	0.0	$0
03EW2174	13.2	$25,261	13.2	$25,261	13.2	$25,261	13.2	$25,261	0.0	$0	0.0	$0	0.0	$0
03EW2175	6.7	$17,630	6.7	$17,630	6.7	$17,630	0.0	$0	0.0	$0	0.0	$0	0.0	$0
03EW2176	3.3	$13,656	3.3	$13,656	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0
03EW2177	3.4	$13,773	3.4	$13,773	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0
03EW2112	5.9	$16,695	5.9	$16,695	0.0	$0	0.0	$0	0	$0	0.0	$0	0.0	$0
03EW2111	51.1	$69,481	49.7	$67,880	49.7	$67,880	49.7	$67,880	49.7	$67,880	0.0	$0	0.0	$0
03EW2110	4.7	$15,340	4.7	$15,340	4.7	$15,340	4.7	$15,340	4.7	$15,340	4.7	$15,340	0.0	$0
03EW2109	19.1	$32,167	19.1	$32,167	19.1	$32,167	19.1	$32,167	19.1	$32,167	0.0	$0	0.0	$0
03EW2107	14.0	$26,160	12.4	$24,291	12.4	$24,291	12.4	$24,291	12.4	$24,291	0.0	$0	0.0	$0
03EW2106	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0	0.0	$0
03EW2105	36.3	$52,174	36.3	$52,174	36.3	$52,174	36.3	$52,174	36.3	$52,174	0.0	$0	0.0	$0
03EW2104	19.1	$32,085	19.1	$32,085	19.1	$32,085	19.1	$32,085	19.1	$32,085	19.1	$32,085	0.0	$0
03EW2102	42.2	$59,115	39.3	$55,726	39.3	$55,726	39.3	$55,726	39.3	$55,726	39.3	$55,726	0.0	$0
03EW2103	26.4	$40,628	26.4	$40,628	26.4	$40,628	26.4	$40,628	26.4	$40,628	26.4	$40,628	0.0	$0
03EW2113	0.0	$0	35.4	$51,169	35.4	$51,169	35.4	$51,169	35.4	$51,169	35.4	$51,169	35.4	$51,169
03EW2114	0.0	$0	9.4	$20,785	9.4	$20,785	9.4	$20,785	9.4	$20,785	0.0	$0	0.0	$0
All EWs		$482,982		$548,076		$503,998		$486,369		$392,244		$194,948		$51,169
SR Plant Costs[1]		$98,063		$98,063		$79,475		$69,559		$0		$0		$0
IP Plant Costs[1]		$176,970		$209,335		$209,335		$209,335		$209,335		$103,833		$29,431
Total Annual Electrical Cost		$758,015		$855,475		$792,808		$765,263		$601,580		$298,781		$80,600

Note:

1. Assumes costs and flow rates from October 2011 - September 2012 as baseline, pro-rated to design flow.

Key:

EW = extraction well

hp = horsepower

IP = In-Plume

SR = Sandwich Road

Table C-5b
Optimized Scenario 7 - Future Lifecycle Cost Summary
Final CS-10 2013 Technical Memorandum: Focused Feasibility Study for Remedial System Optimization

Year	Implementation Costs[3]	Electrical Cost[1]	Monitoring Cost[2]	Total Cost
2012		$758,015	$1,088,807	$1,846,822
2013	$1,995,045	$758,015	$575,150	$3,328,210
2014		$855,475	$1,088,807	$1,944,282
2015		$855,475	$575,150	$1,430,625
2016		$855,475	$994,757	$1,850,232
2017		$855,475	$531,743	$1,387,218
2018		$855,475	$994,757	$1,850,232
2019		$855,475	$531,743	$1,387,218
2020		$792,808	$907,942	$1,700,750
2021		$792,808	$491,953	$1,284,761
2022		$792,808	$907,942	$1,700,750
2023		$792,808	$491,953	$1,284,761
2024		$792,808	$907,942	$1,700,750
2025		$765,263	$491,953	$1,257,216
2026		$765,263	$831,979	$1,597,242
2027		$765,263	$455,780	$1,221,043
2028		$765,263	$831,979	$1,597,242
2029		$765,263	$455,780	$1,221,043
2030		$765,263	$763,250	$1,528,513
2031		$765,263	$423,224	$1,188,487
2032		$765,263	$763,250	$1,528,513
2033		$792,808	$423,224	$1,216,032
2034		$792,808	$763,250	$1,556,058
2035		$601,580	$423,224	$1,024,804
2036		$601,580	$701,756	$1,303,336
2037		$601,580	$394,286	$995,866
2038		$601,580	$701,756	$1,303,336
2039		$601,580	$307,470	$909,050
2040		$298,781	$578,768	$877,549
2041		$298,781	$307,470	$606,251
2042		$298,781	$542,595	$841,376
2043		$298,781	$289,384	$588,165
2044		$298,781	$506,422	$805,203
2045		$80,600	$289,384	$369,984
2046		$80,600	$470,249	$550,849
2047		$80,600	$253,211	$333,811
2048		$80,600	$434,076	$514,676
2049		$80,600	$253,211	$333,811
2050		$80,600	$397,903	$478,503
2051		$80,600	$217,038	$297,638
2052		$80,600	$361,730	$442,330
2053		$80,600	$198,951	$279,551
2054		$80,600	$325,557	$406,157
2055			$198,951	$198,951
2056			$293,001	$293,001
Total	$1,995,045	$23,628,437	$24,738,708	
			Total Lifecycle Cost	$50,362,190

Notes:

1. Assumes costs and flow rates from October 2011 - September 2012 as baseline, pro-rated to design flow.
2. Monitoring costs from table "CS-10 Present Value SPEIM/O&M Costs", *Final CS-10, Ashumet Valley Plumes Updated Interim Remedial Action Report*.
3. Costs for new EW construction, MTU construction & installation from *Final CS-10, Ashumet Valley Plumes Updated Interim Remedial Action Report,* pages 82 & 87.

APPENDIX D

Responses to EPA Comments on the CS-10 Optimization Modeling - Phase II Results Presentation at the 21 March 2013 Technical Update Meeting

APPENDIX D
RESPONSES TO EPA COMMENTS ON THE
21 MARCH 2013 TECHNICAL UPDATE MEETING
CS-10 OPTIMIZATION MODELING - PHASE II RESULTS PRESENTATION

GENERAL COMMENTS:

1. Please describe the process for arriving at the locations, screen intervals, and pumping rates evaluated for the two new extraction wells (03EW2113 and 03EW2114). Please provide a brief discussion of the range of options considered, and the level of confidence on the part of the modeling team that the configurations presented represent a reasonable attempt to identify an optimum to meet the objectives.

   Response: Similar to previous optimization modeling efforts, a manual iterative approach was used to select the optimal locations, extraction well screen intervals, and pumping rates for the two proposed extraction wells. For 03EW2113, the simulated new deep screened extraction well in the area of 03EW2102/03EW2104, the screen interval was chosen to focus the extraction stress on the deep contamination that was delineated in the area and was determined to be outside the system capture zone using the existing infrastructure. The location and pumping rate of new extraction well 03EW2113 was determined based on the results of capture zone analysis followed by numerous contaminant transport model simulations. The primary goal of this extraction well was to capture the deep contamination before it migrated downgradient in order to reduce aquifer restoration timeframes. Therefore, during the iterations the well location and/or pumping rate was revised to balance the cleanup timeframes to the north, south, east, and west of the new well to achieve an optimal restoration timeframe. A reduction of 34 to 38 years in aquifer restoration timeframe was achieved in the scenarios that simulated this new extraction well (Scenario 5 and Scenario 7, respectively) compared to the predictions using Alternative 10 operating conditions presented at the time of remedy selection; so the method used to determine the optimal location, screen setting and flow rate for this new extraction well was very successful and showed significant improvement in remedial system performance.

   Similarly for 03EW2114, the simulated new extraction well in the eastern In-Plume (IP) lobe, the extraction well screen interval was chosen based on the vertical extent of upgradient contamination. The location and pumping rate of new 03EW2114 was determined based on the results of capture zone analysis followed by numerous contaminant transport model simulations. The primary goal in placing this extraction well was to reduce the contaminant mass in the eastern IP lobe by capturing the high concentration area (greater than 100 micrograms per liter [µg/L]), and reducing the extent of downgradient migration of this lobe. Based on existing data, the distribution of contamination in the eastern IP lobe is quite heterogeneous and does not appear to be laterally and/or vertically extensive. The northing coordinate of the extraction well was chosen to be just downgradient of the highest concentrations but still within the known area of contamination above the Maximum Contaminant Level (MCL). Data gap investigation activities are underway in this area and the final placement of this extraction well will be based on all available data if active treatment will be pursued. In the scenarios where this new extraction well was simulated (Scenario 6 and Scenario 7), the eastern IP lobe attenuates below the MCL well north of the Sandwich Road (SR) extraction fence, the restoration timeframe for the eastern IP lobe was

reduced by 10 years, and operation of the SR extraction fence is reduced by 20 years. Based on the existing data and the suspected narrow extent of this lobe, the method used to determine the optimal location for this extraction well was very successful. As noted, a data gap drilling investigation is ongoing in the eastern IP lobe area to further delineate the downgradient extent of the high concentration area and the location and pumping rate for this extraction will be re-evaluated during final well field design modeling if active treatment is pursued.

2. A number of the results for the performance measures are, at first glance, somewhat surprising, although plausible. For the following two observations, please provide qualitative explanations.

   - One of the greatest successes of the potential new infrastructure is the significant shortening of the projected time until restoration of the in-plume domain [from 2106 (Scenario 4) to 2056 (Scenario 7)], yet the estimated date for in-plume system shutdown remains unchanged (2055). This appears to be a consequence of the success of new well 03EW2113 in minimizing the passage of contamination to the deep aquifer downgradient of the central in-plume extraction wells. The in-plume extraction wells, however, lose their connection to the remaining contamination at about the same time under either scenario.

   - The total TCE mass extracted over the history of operation of the system is virtually the same for Scenario 4 and Scenario 7, despite the successes of the two added extraction wells. Is this due to the fact that the contamination captured by the new wells (2113 and 2114) is within the capture zone of existing wells, so eventually it is captured, albeit later? Do the simulations assume that the downgradient extraction wells (e.g., at SR) continue to pump in out years, even if concentrations have fallen to relatively low levels?

   Response: In Scenario 4 and Scenario 7 the estimated date for shutdown of the IP remedial is the same, 2055. This year indicates the date that the last IP extraction well(s) would be taken out of operation. The operational timeframe for each individual extraction well is based on inspection of the animation and assumes the well would be taken out of operation when contaminant concentrations greater than the MCL are no longer located in the immediate vicinity of the extraction well screened interval. Therefore, although the final shutdown date is the same, different configurations are assumed for each scenario throughout system operation. For example, in the case of Scenario 4, extraction wells 03EW2103 and 03EW2104 are assumed to be operational through 2055 and in Scenario 7 these two wells are taken out of operation in 2045 and only the new extraction well 03EW2113 is operational from 2045 to 2055.

   The assumed operation timeframe for each individual extraction well, under each scenario, is also used to determine the mass removal estimates for each scenario. Therefore, more mass is removed by extraction wells 03EW2103 and 03EW2104 under Scenario 4 since these

wells are operational through 2055; 10 years longer than under Scenario 7 operating conditions. Extraction wells 03EW2102, 03EW2103, and 03EW2104 also have much higher flow rates under Scenario 4 than under Scenario 7 (see Table 2 in this report) so the capture zones are more extensive and therefore mass removal estimates are higher. Some of the mass that is captured by the new extraction well 03EW2113 under Scenario 7 operating conditions is captured by existing extraction wells in Scenario 4.

The assumed operation timeframe for each individual extraction well for each scenario is reflected in the electrical cost summary estimates which are presented in Appendix C of this report.

3. Were locations a bit farther south, and screen intervals extending a bit deeper evaluated for 03EW2114? While the configuration tested certainly achieves some successes (e.g., earlier projected shutdown of the Sandwich Road extraction fence), it appears in the animations that a fairly extensive portion of the Eastern Lobe persists at depth downgradient of 03EW2114 in roughly the 2040 to 2050 timeframe. Could this be reduced by placing 03EW2114 farther south, and allowing for a deeper screen?

   Response: Please see response to comment No. 1. The extraction well screen interval for 03EW2114 was chosen based on the vertical extent of upgradient contamination. The location and pumping rate of new 03EW2114 was determined based on the results of capture zone analysis followed by numerous contaminant transport model simulations. The primary goal in placing this extraction well was to reduce the contaminant mass in the eastern IP lobe by capturing the high concentration area (greater than 100 µg/L), and reducing the extent of downgradient migration of this lobe. Based on existing data, the distribution of contamination in the eastern IP lobe is quite heterogeneous and does not appear to be laterally and/or vertically extensive. The northing coordinate of the extraction well was chosen to be just downgradient of the currently delineated high concentrations but still within the known area of contamination above the MCL. During the iterations for the well location and pumping rate of 03EW2114, the easterly coordinate of the well and the pumping rate were varied to reduce the timeframe needed to remediate the high concentration zone, thereby reducing the extent of downgradient migration of this lobe. In the scenarios with this new extraction well (Scenario 6 and Scenario 7), the eastern IP lobe attenuates below the MCL well north of the SR extraction fence, the restoration timeframe for the eastern IP lobe was reduced by 10 years, and operation of the SR extraction fence is reduced by 20 years.

   A data gap drilling investigation is ongoing in the eastern IP lobe area to further delineate the downgradient extent of the high concentration area and the location and pumping rate for this extraction will be re-evaluated during final well field design modeling if active treatment in this area is pursued.